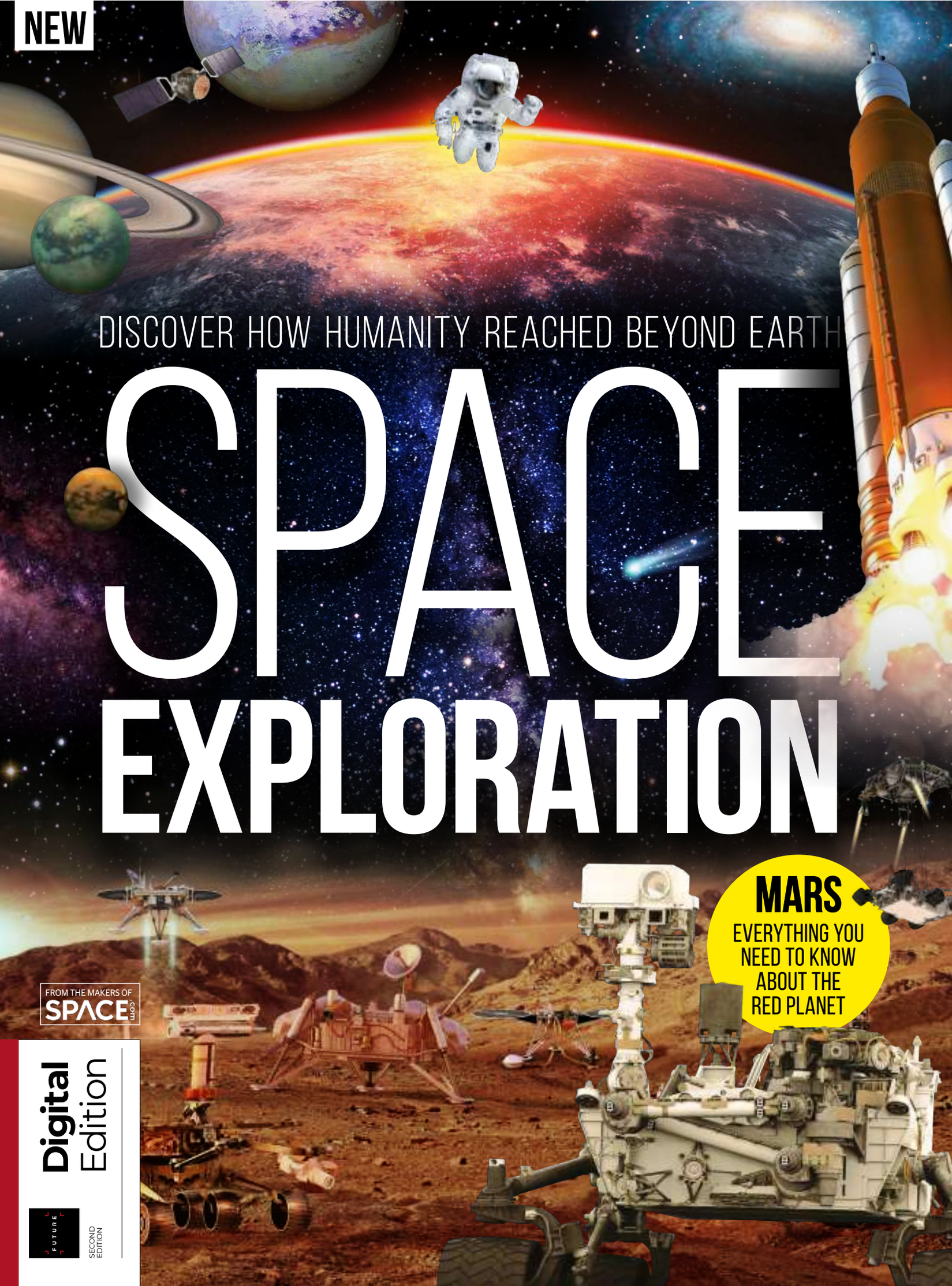

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In this book, we celebrate humanity's space exploration achievements, and look to the exciting missions taking place today on Mars, before asking "Where next?" Turn the page and embark on an unforgettable journey into the reaches beyond Earth.



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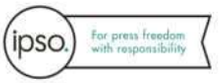
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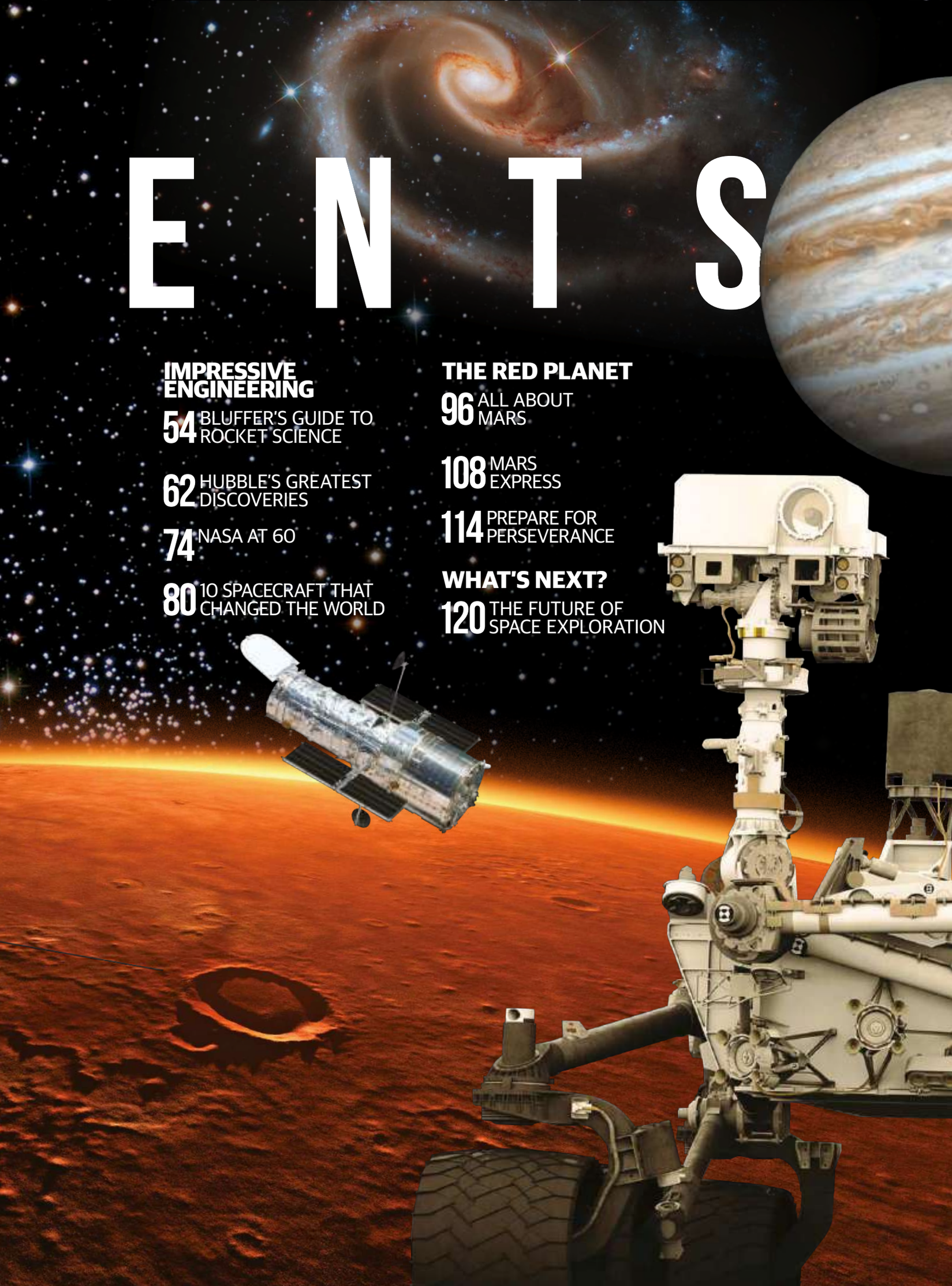
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SPACE FLIGHT BEFORE NASA

The famous US agency has shaped space exploration for more than 60 years – but what led to NASA's formation, and what came before it?

Written by Giles Sparrow



Space flight before NASA

Today NASA, the National Aeronautics and Space Administration, is a byword for the exploration of outer space, ranging from crewed flights to Earth orbit, groundbreaking scientific satellites and robotic exploration of distant worlds. Even when commercial companies or academic institutions take the publicity for new breakthroughs, it's often NASA funding that lies behind them.

The agency was established some 60 years ago, and after winning the Space Race against the Soviet Union in the 1960s, became the undisputed leader in world spaceflight – dwarfing the efforts of other regional agencies such as those of Europe, China and Russia itself. But the story of spaceflight before NASA is far from an all-American triumph – the civilian independent agency was born in a time of national crisis and owed much of its success to advances made in earlier decades and from other countries.

The story begins in the fraught political stalemate at the end of the Second World War. While a wartime alliance between democratic western powers and the communist Soviet Union had been vital to defeating Nazi Germany, the last days of the war saw the newly liberated Europe carved into two major spheres of influence from west and east. The prospect of a new long-term confrontation between former allies was clear, and both sides were keen to seize the spoils of war, including advanced German rocket technology.

While the early 20th century had seen rocket enthusiasts in several countries carrying out experiments and forming societies, the rocket's appeal had been greatest in Germany. Here, scientists and dreamers had been inspired by the writings of early spaceflight advocate Hermann Oberth and their depiction in early science fiction movies. When the Nazi party seized power in the early 1930s, they too saw the rocket's potential as

Above: The 'Bumper' research rocket combined a V-2 lower stage with a small solid rocket upper stage

© NASA

How NASA was formed

The case for an overarching US space authority became clear after the Soviet Union's shock victory in the 1957 race to put a satellite in orbit

1 May 1957
Almost in orbit
The US Naval Research Laboratory fires a dummy satellite onto a suborbital flight path using the first and third stages of its Vanguard rocket.

8 August 1957
Return from space
Wernher von Braun's Army rocket team use a Jupiter-C missile to fire a one-third-scale missile nose cone into space and study its condition after returning to Earth.

4 October 1957
Red star in orbit
The Soviet Union successfully launches the 84-kilogram Sputnik 1 satellite, an orbiting radio beacon whose signals are heard around the world.

8 November 1957
Project Orbiter reprieved
Following the Soviet launch of Sputnik 2, von Braun's team at Huntsville are authorised to begin preparations for a satellite launch as a backup for the Vanguard programme.

6 December 1957
Disaster on the launchpad
The Naval Research Laboratory's Vanguard TV-3 rocket, intended to put the first US satellite into orbit, explodes just two seconds into its flight.

1957 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

a weapon of war. Some German rocket engineers refused to join the military effort, but others found it hard to resist the lure of funding and political support. Most were more interested in spaceflight than warfare, but the engineering problems were the same – reaching space would require a rocket far bigger than anything built so far, and the same rocket would have the potential to deliver a deadly explosive payload across hundreds of miles.

But progress was slow, and by the time the V-2 rocket, masterminded by engineering genius Wernher von Braun, was ready for production, Germany had already been mired in the Second World War for several years. The first rockets to fall on London in September 1944 brought sudden and terrifying death from the skies, but they came too late to affect the outcome of the war as a whole.

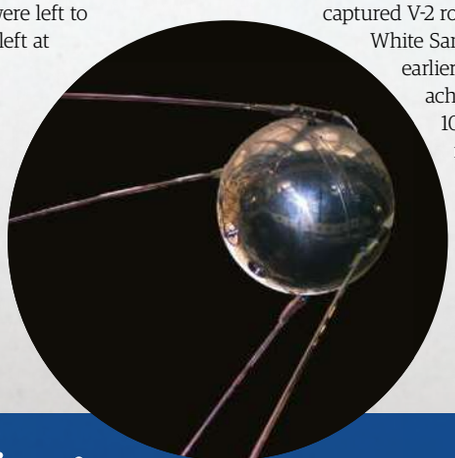
As Germany's defeat became inevitable, the various allied powers were keen to obtain information on the V-2 programme. Von Braun's research centre at Peenemünde lay in the path of the advancing Red Army, but when Soviet soldiers arrived, they found the site stripped and the majority of its staff gone. The German 'rocket team' later surrendered, as they had hoped, to the Americans, while US soldiers also captured the main V-2 factory – a subterranean complex known as Mittelwerk, where inmates of the nearby Mittelbau-Dora concentration camp laboured, and often died, in appalling conditions.

The US Army rapidly began a wholesale relocation of equipment, documents, rocket parts and German engineers to American soil. The recruitment of the V-2 scientists, known as Operation Paperclip, remains controversial to this day, but they would play a key role in the early US space programme and the eventual success of NASA.

The Soviets, meanwhile, were left to gather what fragments were left at Peenemünde and elsewhere, and to sweep up lower-level workers from the area around the V-2 sites. The US, therefore, had a clear post-war advantage in the race for new long-range missiles, with the potential to fly on ballistic trajectories above Earth's atmosphere – its shock defeat in the early days of the Space Race was due in part to the genius of Soviet 'chief designer' Sergei Korolev, but also to mismanagement and political disinterest at home.



"Some German rocket engineers found it hard to resist the lure of funding and political support"



After arriving in the US, von Braun's team were first tasked with reassembling and launching captured V-2 rockets at New Mexico's White Sands Proving Ground. Several earlier V-2 tests had already achieved altitudes of more than 100 kilometres (62 miles), making them the first artificial objects to reach outer space, but the White Sands launches saw the first steps in scientific space exploration. Here, engineers began to work on ways of reaching higher speeds and altitudes, launching scientific instruments on short suborbital 'hops' into space and returning data from orbit.

A landmark came in February 1949 with the launch of 'Bumper 5', which used a modified V-2 to carry a WAC Corporal 'sounding rocket' to a high altitude before releasing it. The Corporal's own engine then took it much higher, reaching an altitude of almost 400 kilometres (249 miles) and returning data about space temperatures and solar radiation via radio signals.

Staying in space, however, was another matter. Boosting a payload to the high speeds necessary to achieve a stable orbit was far beyond even a modified V-2, and although studies carried out around this time concluded that launching a satellite into orbit was technically feasible, they cast doubt on whether the benefits could ever

31 January 1958
The US reaches orbit
The launch of the Explorer 1 satellite on von Braun's Juno launch vehicle puts America back in the Space Race – but with a lot of catching up to do.

7 February 1958
Ending the rivalries
President Eisenhower orders all US federal space projects to be brought under the control of ARPA, part of the Department of Defense.

5 March 1958
The advisors report
Eisenhower receives a formal recommendation from his scientific advisors to establish a new civilian agency controlling all nonmilitary aerospace projects.

2 April 1958
The case for space
Eisenhower sets out the case for US engagement in space exploration and proposes the formation of NASA to Congress and the American public.

29 July 1958
NASA is born
Following approval of the National Aeronautics and Space Act in both houses of Congress, President Eisenhower signs the act into law.

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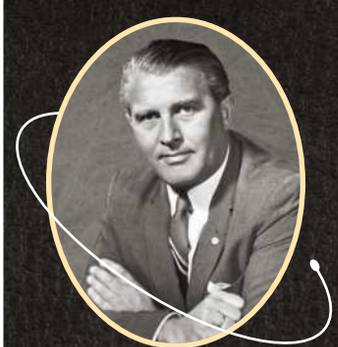
Above: The German 'rocket team' were initially housed at Fort Bliss in Texas

Left: In comparison with US rockets of the time, the Soviet R-7 was far larger and more powerful

Far left: Despite its simple exterior and small size, Sputnik 1 carried a variety of experiments inside

Key figures

These were some of the major players in the early Space Race



Wernher von Braun
The German engineering genius behind the V-2 ballistic missile – after emigrating, he worked on US Army rocket projects while advocating for a large-scale space programme.



Sergei Korolev
As head of the Soviet Union's OKB-1 design bureau he oversaw rocket and satellite development, including the R-7 launch vehicle, the Sputnik satellites and Vostok.



Milton Rosen
Head of the Naval Research Laboratory's Vanguard programme, which after initial failures, successfully launched three of America's first satellites in 1958 to 1959.



James R. Killian
President of the Massachusetts Institute of Technology and chief science advisor to President Eisenhower, Killian headed the committee that recommended NASA's formation.

John B. Medaris
In charge of von Braun's rocket team at Huntsville, he made crucial decisions that permitted a rapid reinstatement of Project Orbiter and the launch of the US' first satellite.





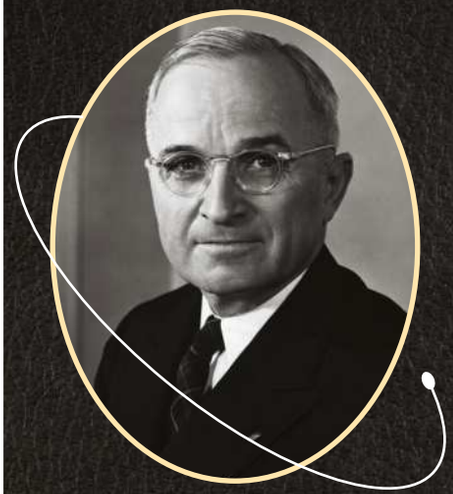
T. Keith Glennan
Appointed by Eisenhower to head the newly formed NASA in 1958, he oversaw the agency's absorption of scattered space projects from across the military and civilian sectors, and helped fashion NASA's long-term goals.

Hugh L. Dryden
The first NASA deputy administrator. He oversaw the development of high-altitude rocket planes and early moves towards US-Soviet cooperation in space research.



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The presidents that paved the way for space exploration



Harry S. Truman
1945 to 1953

Oversaw Operation Paperclip, which imported German rocket scientists to the United States.

Initiated the first US attempts to build an intercontinental ballistic missile, but cancelled them as early as 1947 in favour of 'cruise' missiles that remain in Earth's atmosphere throughout their flight.

Several studies of the potential for satellite launches occurred in his administration, but none led to action.

Generally dismissive of even limited space exploration, describing the idea as "hooey".



Dwight D. Eisenhower
1953 to 1961

Advocated the civilian use of space and fought against its militarisation.

Backed the Naval Research Laboratory's Vanguard satellite launcher over the Army's 'Project Orbiter'.

Announced plans to launch a satellite during the International Geophysical Year of 1957 to 1958.

Led the US response following the unexpected launch of Sputnik 1.

Approved the resumption of Project Orbiter, leading to the successful launch of Explorer 1.

Oversaw the formation of NASA, but in retirement came to doubt the value of manned spaceflight.



John F. Kennedy
1961 to 1963

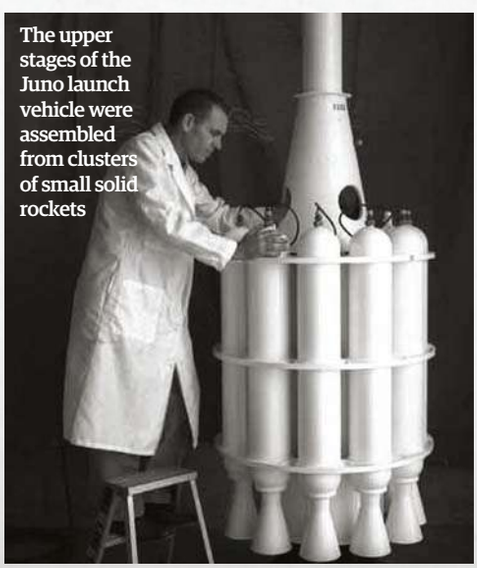
Exploited the supposed 'missile gap' with Russia in order to win the presidency.

Initially argued for international cooperation in space, only to have the offer rejected by Soviet Premier Khrushchev.

Responded to the Soviet launch of Yuri Gagarin, becoming determined that the US should win the Space Race for reasons of both security and prestige.

Oversaw the Mercury programme that put the first US astronauts in orbit.

Committed the US to a manned lunar landing in the 1960s in a May 1961 speech to Congress.



The upper stages of the Juno launch vehicle were assembled from clusters of small solid rockets

outweigh the costs. President Harry S Truman was famously dismissive of the concept of space travel – as late as 1956 he dismissed the concept as "hooey!" – and so rocket research efforts remained focused purely on missiles.

But at just this point, internal rivalries would deal a significant blow to US missile dominance. The Army, Navy and US Air Force (USAF) were each jostling to attract attention and funding to their own missile projects, and the end result was a fudge. The USAF was assigned to build a long-range intercontinental missile called Atlas, and the Army to concentrate on a shorter-range missile, while the Navy would develop a research rocket called Viking.

As Army employees, von Braun and his team were left to look on as the USAF absorbed most of the rocket funding, while dawdling over development of Atlas – a vehicle capable of achieving their dreams of spaceflight. Their own 'Redstone' project, named after the Army arsenal in Huntsville, Alabama, where they were now based, presented relatively few new challenges, and was ready for flight by 1953.

So, in 1951, the sidelined advocates of spaceflight began a concerted PR offensive. Willy Ley, a well-known science writer who had fled Germany for the US before the war, organised a symposium on space travel in New York. This led to a series of wildly popular articles in *Collier's* magazine, outlining von Braun's vision for the colonisation of the Solar System. Walt Disney soon adapted the articles into a three-part television series, and astronaut suits began to outsell cowboy outfits as America went space-crazy.

The political winds were shifting, too. 1952 saw the announcement of a forthcoming International Geophysical Year (IGY) in 1957 to 1958 – an opportunity for scientific cooperation across the Cold War barriers, and an ideal time, many argued, to launch the first satellites. It also saw the election

© NASA; Bettmann / Getty;

of Dwight D Eisenhower, a new president who was far more open to the potential of space travel.

In mid-1954, von Braun was asked to join a top-level conference discussing possible satellite launch options. His solution was 'Project Orbiter', a modified Redstone missile topped with smaller solid-fuel rockets that would fire in clusters to act as two upper stages. Von Braun and his colleagues approached respected scientist James Van Allen to design the instruments for the satellite.

But when the US revealed its plans for a satellite launch during the IGY in December 1955, Project Orbiter was no longer in the frame. Rival scientists had launched a concerted attack, sniping at von Braun's design as awkward and risky, and arguing that taint of the V-2 and use of a military missile would diminish what should be an all-American triumph. Eisenhower, who had his own concerns about the potential militarisation of space, was persuaded to abandon Project Orbiter in favour of the Navy's Viking-based Project Vanguard. Meanwhile, the Soviet Union announced plans of their own to launch a satellite during the IGY, though few in the west took them seriously.

Von Braun's consolation prize was a contract to carry out limited sub-orbital space launches using the lower stages of Project Orbiter to investigate the effects of atmospheric re-entry. It was this project, known as Jupiter-C, that successfully returned the first object from space, a modified missile nose cone, in August 1957.

In the following months, the long prelude to the Space Race neared its endgame. While the Navy rushed to test the stages of its Vanguard rocket, the Soviet Union was secretly preparing a space shot of its own. From a weak starting position, Sergei Korolev and his engineers had accomplished a remarkable feat in building the R-7 missile – a monster rocket whose first stage consisted of four boosters, each larger than a V-2, clustered around a central core. An upper rocket stage gave the R-7 the capacity to put a satellite in orbit – one much larger than the grapefruit-sized objects being prepared for launch by Vanguard.

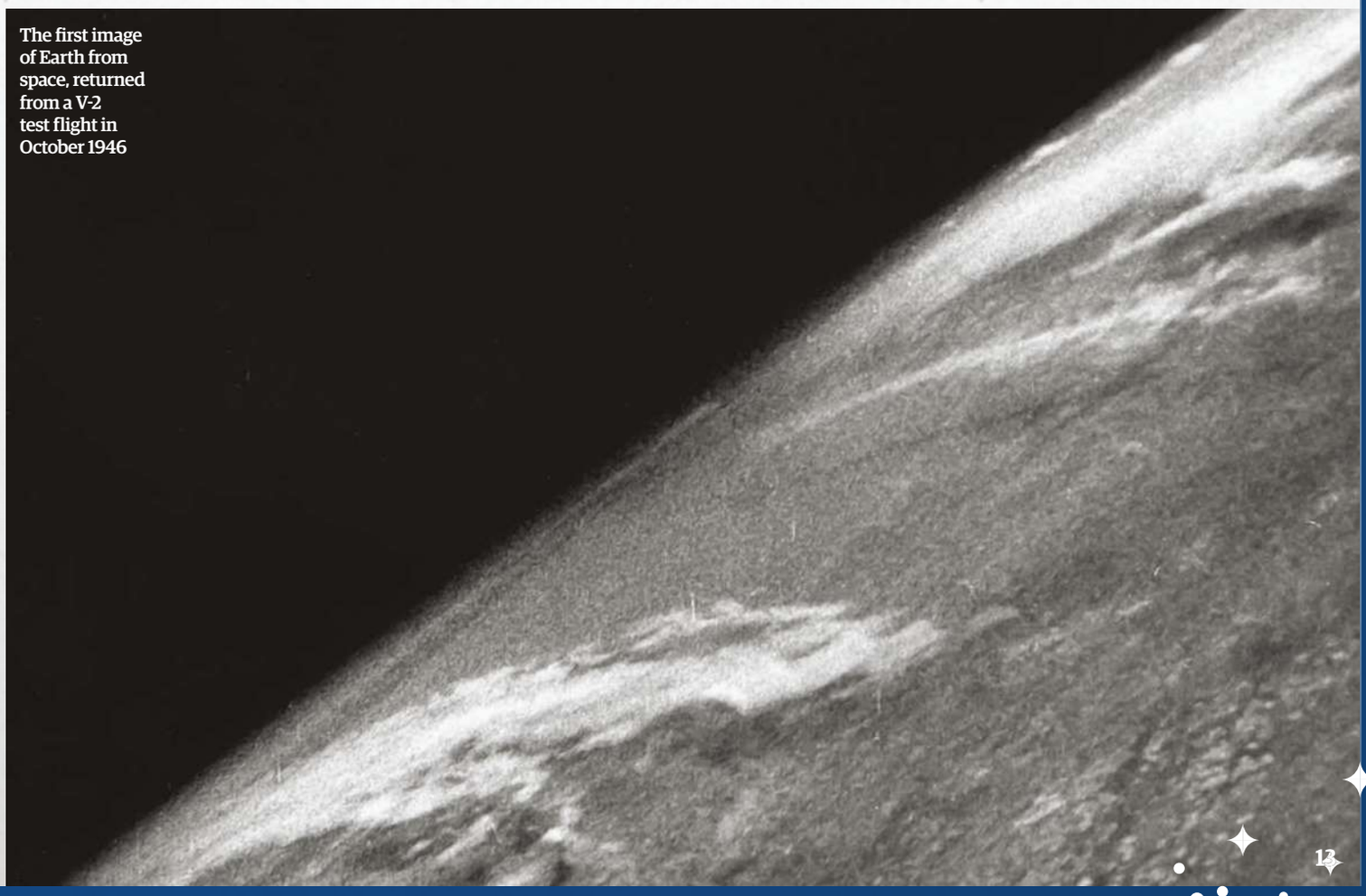
The Soviets played their hand with immaculate timing on 4 October, just as an IGY conference was meeting in New York. The launch of Sputnik 1 sent shockwaves around the world, and the media rushed to print stories about just what the new artificial moon could mean for the balance of global power.

As stunned Americans looked to their government for a response, Eisenhower coolly congratulated the Soviets on their launch of a 'small ball' into space, and indicated that a Vanguard satellite launch would go ahead as planned in early December. This was somewhat deceptive as no definite launch date had yet been set, and the routine response concealed surprise behind the scenes.

One person who remained calm, however, was Wernher von Braun. Questioned by the Secretary of



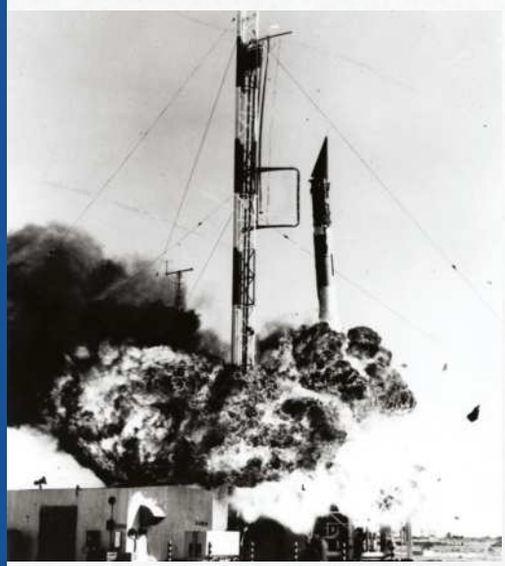
Right: President Eisenhower (centre) with NASA deputy administrator Dryden (left) and administrator Glennan (right) at their swearing-in ceremony



The first image of Earth from space, returned from a V-2 test flight in October 1946



Left: The Project Orbiter committee that met to discuss US satellite launch options in 1955 – note von Braun in the foreground



Below left: The Vanguard TV-3 launch explodes above the launch pad at Cape Canaveral



Right: William H Pickering of California's Jet Propulsion Laboratory, James Van Allen and Wernher von Braun hold up a model of Explorer 1 at a press conference after the successful launch

"The successful launch of Explorer 1 restored some honour to the US space programme"

Defense, he insisted that a restarted Project Orbiter could launch a satellite in 90 days. But it was not until November – after the Soviets had launched the larger and far more sophisticated Sputnik 2, carrying space dog Laika – that Eisenhower overcame his qualms and gave the go-ahead.

The wisdom of this 'insurance policy' became clear in early December when the first fully assembled Vanguard rocket blew up moments after launch. The press and other media, who had gathered in huge numbers expecting to see the first US satellite launch, nicknamed it 'Flopnik'.

Despite the groundwork laid, von Braun's team still had to race to meet their launch target of late-January 1958. Cosmetic changes to the rocket, including renaming it 'Juno', helped distance it from its military origins, but a satellite had to be built from scratch. The eventual design, dubbed 'Explorer 1', was a modified solid rocket casing with the top half allocated to Van Allen's scientific instruments – the bottom remained a functional rocket, turning Juno into a four-stage launch vehicle.

The successful launch of Explorer 1 on 31 January 1958 restored some honour to the US space programme, but America was still clearly lagging behind Soviet achievements. As the Space Race began in earnest, ideas flew around for everything from spy satellites to manned spacecraft. The USAF, eager to make up for the Army and Navy's dominance in space so far, developed several options for a 'Man in Space Soonest' Project. These included rocket-powered 'X-planes', experimental aircraft designed in conjunction with NACA, the National Advisory Council on Aeronautics, and a manned capsule launched by a converted Atlas missile.

Anxious to avoid further damaging rivalry, President Eisenhower ordered that all space projects should be temporarily brought under the control of the Defense Department's Advanced Research Projects Agency (ARPA). He also asked a committee of advisors to draw up long-term plans for a national space science programme.

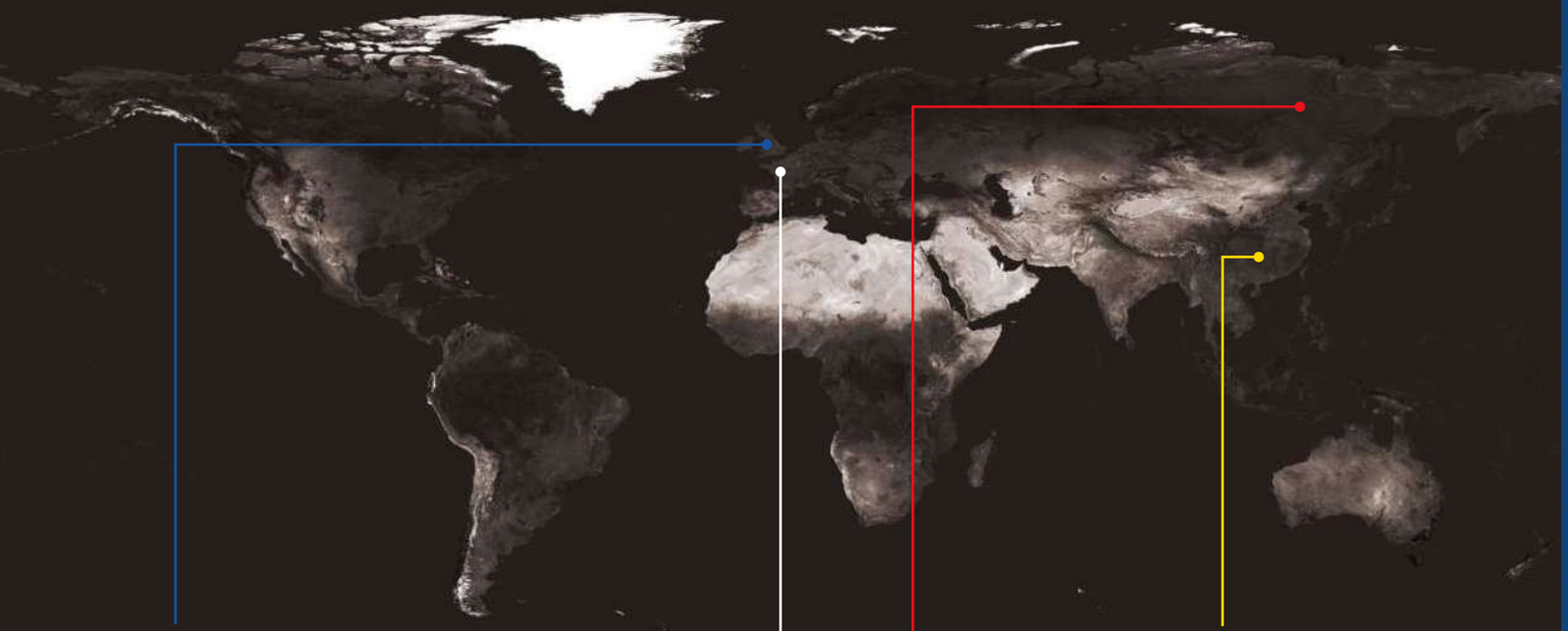
A few weeks later, the committee delivered its recommendation for a new civilian space agency that would succeed NACA and control all US space projects, except for those with explicitly military applications. On 2 April, Eisenhower gave the idea his formal backing, calling for the establishment of a 'National Aeronautical and Space Agency' with wide-ranging powers and responsibilities. With legislation passed by both houses of Congress, NASA came into being on 29 July 1958.

In the years that followed, the new agency would absorb many of the pre-existing US space efforts. Von Braun's team at Huntsville, for example, would form the core of the new Marshall Space Flight Center, while research for 'Man in Space Soonest' would prove useful in designing the Mercury capsule that eventually carried the first Americans into space. NASA's creation may have ended a fascinating period in space history, but it brought much-needed focus to the US space effort – and while there would be plenty of other setbacks along the way, without NASA, the race to put astronauts on the Moon and seal victory in the Space Race might have played out very differently.

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The rest of the world

While America's space programme was to have the greatest influence on the future, the US was not the only country racing for space in the years after the Second World War



United Kingdom

1945 to 1971

Britain's 'Operation Backfire' tested captured V-2 rockets shortly after World War II, and the UK developed its own ballistic missile and launcher development programme before it was cancelled due to budget cuts in the early 1970s.

France

1945 to present

France pursued its own missile programme after World War II. A space agency was established in 1961 and the first French satellite, Asterix, was launched in 1965. From the 1970s, France became a leading member of the European Space Agency.

Soviet Union

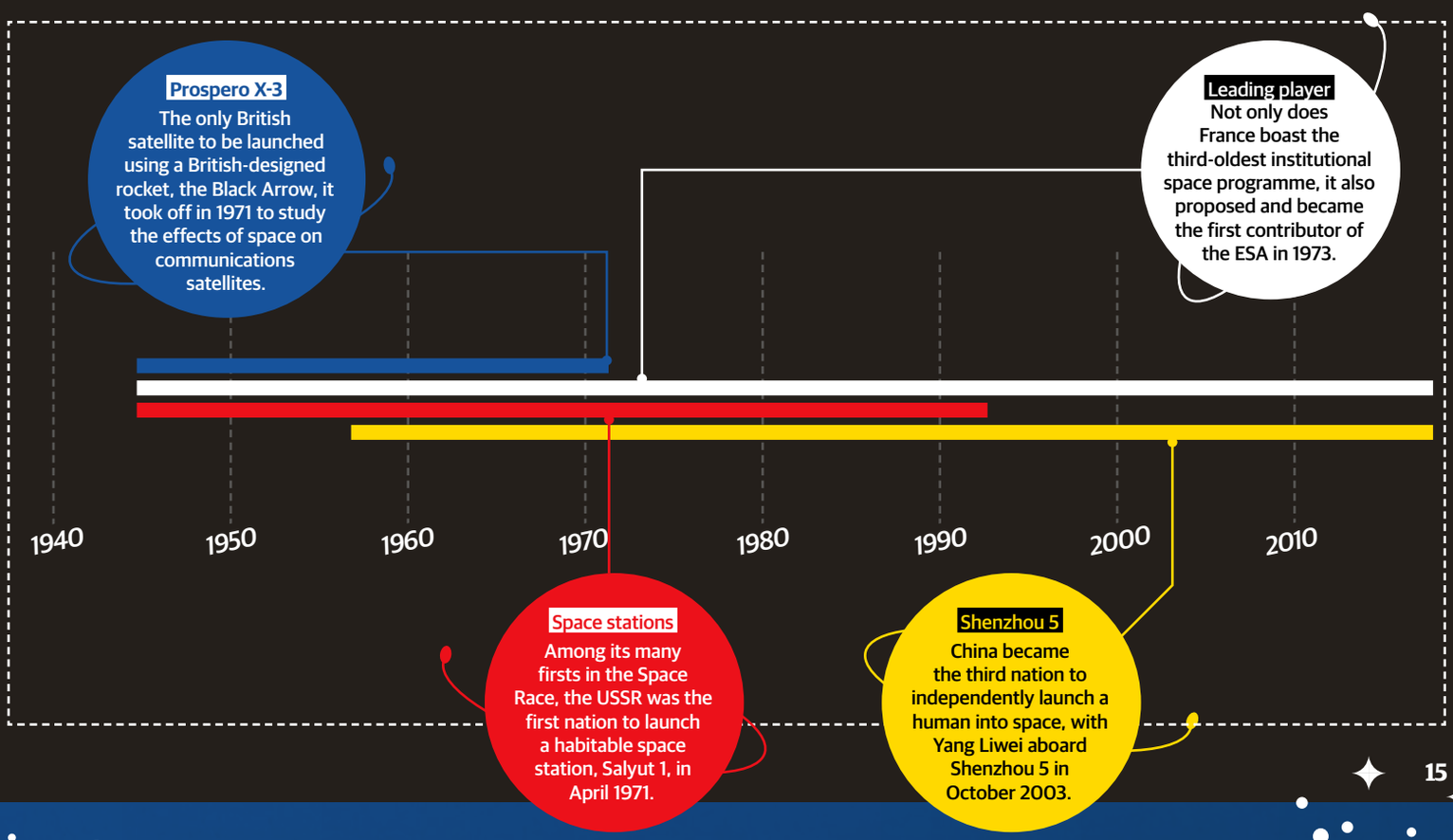
1945 to 1991

Political will and engineering genius gave the Soviets an early lead in the Space Race, which faltered after Korolev's death in 1966. Nevertheless, the Soviet Union continued as a major power until its dissolution, and Russia inherited much of its space knowhow.

China

1957 to present

China sought to develop its own space programme following the launch of Sputnik 1 in 1957. Initially, the Chinese benefited from technology shared by the Soviets, but after relations cooled, progress slowed.



SENDING SPUTNIK to SPACE

Designed in a race against the Americans, the Soviet Union not only crossed the finish line, but with the launch of a simple satellite began an era of space exploration

★ Written by Scott Dutfield ★

It was the satellite that fired the starting gun for the Space Race between two world powers. Designed to simply observe the Earth's atmosphere, Sputnik began a wave of technological achievements and became the Soviet Union's national treasure.

Following the end of the Second World War, both the United States and the Soviet Union had entered into the Cold War, beginning in 1947. A political and economic battle placed the nations at loggerheads. Both focused on the development of advanced military weaponry, including the creation of intercontinental ballistic missile (ICBM) technologies. Taking inspiration from the Germans' explosive endeavour, the V-2 rocket, the possibilities for nuclear warhead missiles became a growing concern and goal for both nations. However, in the early 1950s, sights were set on the heavens due to the role rockets could play in entering a new field of exploration – space.

After a period of global diversity during the war, in 1952 National Academy of Science member Lloyd Berker proposed to the International Council of Scientific Unions (ICSU) a series of global geophysical activities. The project aimed to conduct a series of collaborative studies to further understand the Earth and its environment over a fixed period of time. Running from July 1957 to December 1958, this window of scientific exploration was known as the International Geophysical Year (IGY). From glaciation to gravity, over 70 countries took part in projects that would lead to the understanding of plate tectonics and polar regions and the discovery of the Van Allen radiation belt.

In July 1955, United States President Dwight Eisenhower announced the country's aim to launch an artificial satellite as part of the IGY, stating that: "The most important result of the International Geophysical Year is the demonstration of the ability of peoples of all nations to work together harmoniously for the common good. I hope this can become a common practice in other fields of human endeavour." Seeing this announcement as a challenge, the Soviet Union followed suit, announcing its plans to achieve the same feat a month later. The rebuttal, however, was not based on an existing project already in motion, rather a consequence of the Cold War.

The Second World War had played host to the latest rocket weapons. However, none of these was capable of launching a satellite. In order to achieve this astronomical feat of engineering, a satellite would first need a way to surpass the

History was made in 1957 as mankind's first artificial satellite, Sputnik, reached space

The former USSR released a commemorative stamp to celebrate Sputnik's success



A CASE OF MISTAKEN IDENTITY

FLYING HIGH IN THE SKY, MANY THOUGHT THEIR GAZE HAD CAUGHT A GLIMPSE OF A PASSING SATELLITE. HOWEVER, NOT ALL WAS AS IT SEEMED

Met with the announcement of the first satellite launched into space, many people in both the Soviet Union and the United States rushed outside to see Sputnik for themselves. Due to Sputnik's aluminium appearance, the elliptical satellite often found itself catching the Sun's rays, illuminating its position in the sky. In fact, Sputnik was so reflective it could be seen from Earth's surface through a pair of binoculars – and, if bright enough, even the naked eye. Accompanied with its onboard radio beacon, Sputnik's shiny surface could also be used to locate its position around the globe during orbit.

Curiosity and concern over the satellite's existence formed a following of public observers, each trying to catch a glimpse of the revolutionary tech. On one fateful day in late 1957, officials received a rush of sightings claiming to see Sputnik clearly in the sky. However, their mass excitement is believed to have been the result of misidentification. In fact, what was thought to be Sputnik was indeed the rocket that had sent the satellite to space, the R-7. Sputnik wasn't alone in reaching orbit, because the rocket's 26-metre-long core stage went with it. It was also covered in reflective panels, placed for visual tracking of the rockets return. The rocket fell back to Earth in December 1957, aligning with the reported sighting.

Sending Sputnik to space



Researchers used Sputnik's beeps and calculated trajectory to track its movements around the Earth



Sputnik's rise to fame resulted in the creation of toys to show the next generation Sputnik's triumphal orbit of the Earth

Earth's gravitational pull. Recognised as a leading expert in aeronautical engineering, Sergei Korolev, chief designer in the field, was a natural fit for undertaking the task of creating the Soviet's first ICBM. Heading the OKB-1, an aeronautical design bureau, Korolev and a team of the country's finest engineers – including engineer and aeronautical designer Mikhail Tikhonravov – began work on achieving the seemingly unachievable. Taking inspiration from the German V-2, Korolev developed the R-7 rocket, a 267-ton liquid-fuelled missile capable of around 396.9 tons of thrust. Stemming from the fruits of several versions, the R-7 promised to be the first rocket to see space. Now with a method of delivery, attention turned to the satellite itself.

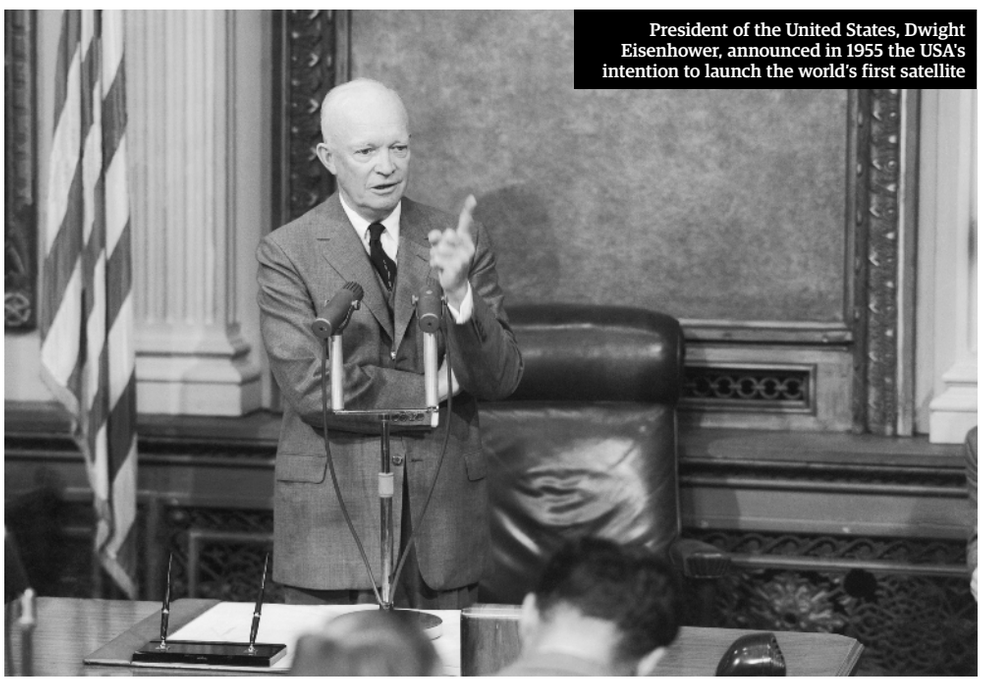
By January 1956 Korolev's vision for the creation of a satellite had been approved by the Soviet Presidium of the Central Committee. Originally constructed under the codename 'Object D', this new form of technology was limited to a weight of between 1,000 to 1,400 kilograms to enable its journey aboard the R-7 rocket, sitting at the head. Several versions of Object D were designed, equipped with the latest in observational technologies. Object D housed receivers and transmitters to transmit measurements and data to stations back on Earth. Aviation technologies were incorporated in order to study areas such as the Earth's gravitational field, shape, ionosphere and space radiation, to name just a few. However, due to the IGY claim set by the United States, the predicted completion and launch of Object D crossed the window of opportunity, and so a simpler spherical alternative was considered.

'Prosteishy sputnik', or 'simplest satellite', became the Soviets' stand-in satellite. Simplified in size, weight and equipment, the Sputnik satellite, also known as PS, was designed to be completed and launched by the end of 1957. Only 83.6 kilograms in weight and 59 centimetres (23 inches) in diameter, the first Sputnik satellite was made by fusing two aluminium hemispheres only two millimetres thick. Polished to perfection for easy detection, the futurist sphere extended two long antennae, finalising its now-unmistakable appearance. A technological downgrade from its predecessor, Object D, housed in the sphere was a simple radio beacon for telemetry back down to Earth. This simplistic design allowed the Soviet engineers to create a functional satellite well within the window of the IGY deadline. On 4 October 1957 at a Soviet Union testing facility in the Kazakh Republic, history was made with the launch of the Sputnik satellite. Partnered with the R-7 rocket, the elliptical sphere thrust into the atmosphere and escaped the skies into space.

After the rocket successfully left the atmosphere, Korolev and his team waited anxiously, ears pointed at the radio receiver. After a few moments, simple beeps sounded from the radio and cut the tension that filled the air. Signalling the satellite's success, the beeps lasted for around two minutes before signal was lost as Sputnik continued on its journey around the Earth. As those first few beeps came through the airwaves, the Soviet Union had secured its place as the leader in space



Sputnik's success became a hot topic among the press in both the Soviet Union and the United States



President of the United States, Dwight Eisenhower, announced in 1955 the USA's intention to launch the world's first satellite



The third generation of Sputnik satellites was launched in 1960 to study the Earth's magnetic field

> "On 4 October 1957 at a Soviet Union testing facility in the Kazakh Republic, history was made"

exploration to the world. Met with roaring applause by the Soviet Union, these simple beeps signified not only the satellite's safe arrival into space, but the object's position in orbit, mapping the world. Travelling at around 30,000 kilometres (18,641 miles) per hour, Sputnik took 96 minutes to orbit the Earth, lasting three months before burning up on re-entry.

Sputnik mania swept the USSR. Commemorative stamps and even toys of the satellite's journey were made to celebrate its success. This venture into space had awakened the world to the power of the Soviet Union, who now saw themselves as the rightful pioneers of space. Korolev was once quoted as saying: "The Soviet Union has become the seacoast of the universe."

The once-unthinkable feat of reaching for the stars was now a reality. However, the achievement wasn't seen by all as a testament to mankind, but a threat to their freedom. The announcement of Sputnik's short-lived survival in space was initially met with congratulations in the US by President Eisenhower. However, messages of goodwill soon shifted into a frenzied panic at the potential military threat to their nation, commonly known as the Sputnik crisis. Though it is believed that President Eisenhower and the US government were aware of the Sputnik satellite prior to its launch, the impact it would have on the world was greatly underestimated. What hit the American people was fear. Fear that the Soviet Union may have weaponised space. Fear that America had fallen behind as the world's technological authority they had once been held as. Such a small, insignificant satellite (especially when compared to modern-day creations) had sent a world power into utter disbelief, and fuelled the fire of its space programme. And so the starting pistol for the Space Race had officially fired.

The United States achieved its venture into space in January 1958 by launching Explorer I. Again, however, the achievement was overshadowed by the success of Sputnik 2, which delivered a dog into space only a few months after the launch of the first Sputnik. Though Sputnik had initially sparked outrage throughout the United States, as a result of its success, one of the world's most respected and advanced organisations was born. Fuelled by the fire to regain their technological authority, American officials created the Advanced Research Projects Agency (later renamed DARPA), and in October 1958 the National Aeronautics and Space Administration (NASA) was established to further the work of the National Advisory Committee for Aeronautics, founded in 1915.

The two nations battled it out during the years that followed, with the Soviet Union claiming the record of putting the first man into space and woman into space. Though born from the battlefield, Sputnik's creation was a feat of not only rocket engineering, but that of scientific investigation. It sparked an era of discovery and exploration like no other. Arguably the mascot of the Space Race, Sputnik will forever be seen as a beacon of possibility.



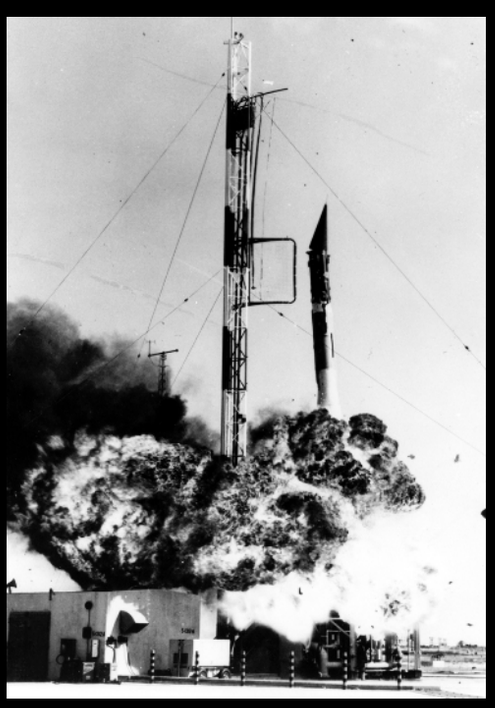
Signalling its survival in space, Sputnik's beeps could be heard on a regular radio, allowing not only the Soviet Union to listen in...

'FLOPNIK'

ALTHOUGH ACHIEVING SUCCESS IN SPACE IN 1958, THE UNITED STATES' EXPLORER I SATELLITE WAS NOT ITS FIRST ATTEMPT AT REACHING THE STARS

Invigorated by Sputnik's success, America's own artificial satellite, the Vanguard, promised a more advanced analytical prowess to collect data from space. As a counterpart to Sputnik, though behind in the Space Race, Vanguard was set to launch in December of 1957. The long-awaited and highly publicised satellite was America's attempt to regain confidence in the country's ability to rival the Soviet Union. Similar in size and shape to Sputnik, the officially titled 'Naval Research Laboratory Vanguard TV3' (Test Vehicle 3) utilised a three-stage Vanguard rocket and was said to be capable of studying the effects of space's environment on the satellite, and the ability to take geodetic measurements of Earth.

However, Vanguard's journey to outer space was cut short. Launching from Florida's Cape Canaveral, the satellite and accompanying rocket only made it just over one metre off the ground before tragedy struck. Unfortunately, due to a fuel tank failure, the rocket and its satellite passenger crashed back down to the ground in a spectacular explosion. It is still unknown as to the exact cause of the rocket's misfortune, though there was speculation burning fuel had entered the fuel system before propellent pressure had been achieved. During the height of the Cold War, this was yet another blow to the USA's confidence in its space abilities, with press dubbing the satellite 'Flopnik'. The failure was not long-lived, however, and by the following March of 1958, the next-generation Vanguard 1 made a successful trip into space.



Flames engulfed the fuel tanks of the Vanguard rocket, causing a massive explosion during launch

© Getty Images



RISE *OF THE* SPACE AGE

Shadowed by fear of war, the initial launch of Sputnik revealed humanity at its most bold

Written by Ben Evans

Six decades ago, the world stood still, gazed at the sky and listened through shortwave radio receivers with fascination and fear. For millennia, humans had clung to the Earth's surface, only recently having mastered the long-held dream of flight and with scant awareness of what lay beyond the thin veil of the atmosphere. But, on 4 October 1957, our sense of place in the cosmos changed forever. Over three weeks, a steady 'beep-beep' transmission from Sputnik 1 – the first artificial satellite – heralded the dawn of the space age. Yet the euphoria of conquering space was met by harsh Cold War reality, as Russia and America sought to deliver weapons of enormous destruction across intercontinental distances.

For something which changed the world, Sputnik 1 was an unremarkable icon. It was a polished metal sphere, 23 inches across, with four antennas to broadcast radio pulses at 20.005 MHz and 40.002 MHz, easily audible to amateur radio listeners. Circling the globe at 65-degrees of inclination, its flight path carried it over virtually the entire inhabited Earth, completing an orbit every 96.2 minutes. Its signal vanished when its batteries died, and the 184-pound satellite burned up in the atmosphere in January 1958.

Thus began the space race between the capitalist United States and the communist Soviet Union to attain mastery over the heavens. Following World War II, both nations used captured German scientists and rockets (including the infamous V-2) to further their ambitions of building intercontinental ballistic missiles to establish technological and ideological supremacy over the other. Juxtaposed against this bellicose stance was the 1957-1958 International Geophysical Year, a concerted 18-month campaign of Earth science research. In the summer of 1955, the United States and the Soviet Union pledged to launch a satellite during the IGY.

Politically, Sputnik 1 was a great shock and demolished Western perceptions of Russia as a backward nation of potato farmers. Science fiction writer Arthur C Clarke reflected that on 4 October 1957, the United States became a second-rate world power, while economist Bernard Baruch praised the Soviets' "imagination to hitch its wagon to the stars" and stressed that American paranoia was well-founded. During his 1960 presidential campaign, John F Kennedy played into this palpable sense of national dread by claiming that Soviet hegemony in space could someday afford them control of the Earth.

After the 'Sputnik crisis', political figures increasingly spoke of a 'gap' in missile-building technology, with the United States falling behind the Soviet Union. Indeed, the Soviets created the world's first intercontinental ballistic missile – the R-7 – and test flew it across a distance of 3,700 miles, before using a modified version to launch Sputnik 1. Remarkably, the same basic rocket is still used to launch satellites and humans today. The missile gap was promulgated by the Gaither Report in November 1957, which recommended a significant strengthening of US military might. Its figures were exaggerated, but the fiction of a missile gap galvanised America into forming NASA in October 1958, and accelerated the development of rockets to send men into space.

America's ascendancy in space began with disappointment. In December 1957, a Vanguard rocket exploded on the launchpad, triggering a media frenzy. Journalists mocked it as 'Kaputnik', while Soviet delegates to the United Nations tauntingly wondered if the United States needed aid as an "undeveloped nation". Finally, on 31 January 1958, Explorer 1 became America's first successful satellite. Six weeks later, it was followed by Vanguard 1, disparagingly nicknamed "the grapefruit" by Soviet Premier Nikita Khrushchev. However, the smallness of these early satellites belied their advanced scientific capabilities. Explorer 1 discovered the Earth's Van Allen radiation belts, while Vanguard 1 remains the oldest man-made object still in orbit today.

The benefits of satellites for a range of applications – from communications to reconnaissance and navigation to scientific research – had long been recognised, and in December 1958, the first test of a relay was used to broadcast Christmas greetings from US President Dwight D Eisenhower. Two years later, Echo 1 became the world's first passive communications satellite, followed by Telstar, which transmitted television pictures, telephone calls and telegraph images, as well as a live transatlantic feed between the United States and Belgium.

It was Arthur C Clarke who first widely disseminated the idea of putting satellites into 'geostationary' orbit, more than 22,000 miles above the Earth, matching the planet's rotation for worldwide communications. Syncom 3 was first to reach this high orbit, relaying images from the 1964 Summer Olympics in Tokyo. This laid the foundation for hundreds more communications



To date, 12 people have left their footprints on the Moon

© NASA, Getty/Bjorn Holland

The Great Space Race

From tiny satellites to boots on the Moon, humanity took great strides in a single decade



UNITED STATES — *1955* — **SOVIET UNION**

4 October 1957
Sputnik 1, world's first artificial satellite.

3 November 1957
Sputnik 2, carried first living creature into orbit.

31 January 1958
Explorer 1, America's first satellite.



12 September 1959
Luna 2, first mission to crash-land on the Moon.

1960

4 October 1959
Luna 3, first images of the far side of the Moon.

5 May 1961
Alan Shepard, America's first man in space.

12 April 1961
Yuri Gagarin, first man in space.

20 February 1962
John Glenn, America's first man to orbit the Earth.

16 June 1963
Valentina Tereshkova, first woman in space.

3 June 1965
Ed White, America's first spacewalk.

15 December 1965
Gemini 7 and 6, first rendezvous in space.

18 March 1965
Alexey Leonov, first spacewalk.

16 March 1966
Gemini 8, first docking in space.



24 December 1968
Apollo 8, first mission to orbit the Moon.

21 July 1969
Apollo 11, first piloted landing on the Moon.

1970



Sputnik's radio signal was easily detectable, even by using amateur equipment





The US eventually overtook the USSR and won the space race

satellites, which continue to deliver telephone and television services, as well as radio broadcasts and internet access.

Of course, the Cold War inspired less peaceful activities, too, and planning for reconnaissance satellites was set in motion early in the space age. However, it was only after the infamous shoot-down of Gary Powers' U-2 reconnaissance aircraft in May 1960 that the need for military eyes in space became commonplace. In August of that year, Discoverer 13 became the first satellite to return an object safely to Earth, in the form of a classified film canister. Less than two weeks later, the Soviets brought their Korabl-Sputnik 2 spacecraft, carrying the dogs Belka and Strelka, back home. It was the first time that living creatures had been launched into orbit and returned alive.

Sending living creatures, and eventually humans, into space was an important driving force. In November 1957, the Soviets launched Sputnik 2, carrying a dog, Laika. Several animals had already flown above the 62-mile-high 'Kármán line' – the internationally recognised boundary for the edge of space – but three-year-old Laika was first to actually achieve orbit. Following a stressful launch, in which her heart rate more than doubled, Laika died within hours, when the cabin overheated. Her legacy is that she unmasked some of the unknowns about the survivability of launch, orbital acceleration and the effects of weightlessness. Laika laid the groundwork for the 108-minute orbital flight of Yuri Gagarin, the first man in space, on 12 April 1961.

"The pendulum shifted in the mid-1960s, and truly America took the lead"

If Sputnik 1 shocked the world, then Gagarin's mission shocked it again, particularly as it occurred only months into the administration of President John F Kennedy. Matters worsened when CIA attempts to overthrow Fidel Castro failed, leaving Kennedy humiliated, and in need of a means to re-establish his nation's prestige. Although Alan Shepard became America's first man in space on 5 May 1961, his Redstone booster was only capable of a 15-minute suborbital flight. Not until the following year did John Glenn – riding the larger, more powerful Atlas rocket – actually achieve orbit.

Despite such limited spaceflight experience, Kennedy told a joint session of Congress that he intended to direct the United States to land a man on the Moon, before the end of the decade. It was a challenging gamble, since lunar exploration had been pioneered by the Soviets. In January 1959, Luna 1 became the first man-made object to reach the Moon, measuring the solar wind, and eventually entering heliocentric orbit. Before the year ended, Luna 2 had been intentionally crashed into the surface, and Luna 3 returned the first photographs of the Moon's far side, never before

© NASA ; NASA/JPL; U.S. Navy; ESA/Dr. Ralph O. Schill; Science Photo Library / Alamy Stock Photo, Francisco Romero Ferrero; Dinesh 317; Aaron Logan; Carl D. Howe; Brian.gratwicke; Christian Fischer; Husky

Animals in Space The animal kingdom paved the way to space for humankind



Fruit flies 20 February 1947
First animals sent into space, launched to a 68-mile altitude by a V-2 rocket for a radiation exposure study. The fruit flies were recovered alive.



Tsygan and Dezik 22 July 1951
The two dogs reached an altitude of 62.7 miles, and became the first living 'higher' organisms to be recovered alive following a spaceflight.



Félicette 18 October 1963
Paris street cat Félicette is the only feline to have launched into space and returned alive, completing a 15-minute suborbital flight.



Bullfrogs 9 November 1970
Launched on the Orbiting Frog Otolith mission, two were flown to examine their inner ears and understand more about motion sickness.



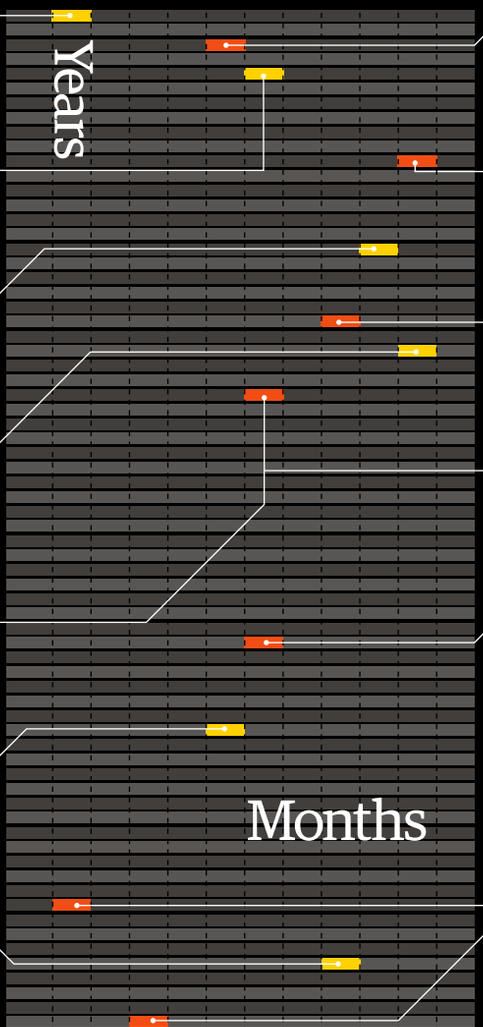
Anita and Arabella 28 July 1973
These two garden spiders took a long time to adapt to weightlessness and spun thinner webs than on Earth. Anita and Arabella died during the mission.



Jellyfish 5 June 1991
Almost 2,500 Moon jellyfish flew aboard the shuttle, in order to study their nervous systems and the impact of weightlessness on their swimming.



Tardigrades 14 September 2007
During Europe's Foton-M3 mission, tardigrades were able to survive ten days of exposure to space, with only their natural protection.





Albert II 14 June 1949
Rhesus monkey Albert II rode a V-2 rocket to an altitude of 83 miles, but died on impact with the ground after suffering a parachute failure.



Laika 3 November 1957
Although she was not the first dog to enter space, Laika – a stray picked up on the streets of Moscow – was the first living creature to enter orbit.



Tortoises 14 September 1968
Along with other biological organisms, two Horsefield's tortoises were the first living creatures to orbit around the Moon and return safely to Earth.



Mummichog 28 July 1973
Two mummichog fish flew aboard America's Skylab space station, initially swimming in tight circles before adapting to weightlessness.



Newts 10 July 1985
Ten newts flew aboard the Bion 7 spacecraft. Part of their front limbs were amputated to allow studies of regeneration in space.



Nematodes 1 February 2003
A live group of nematodes, or roundworms, remarkably survived the destruction of shuttle Columbia, which broke up during re-entry.



Mice 14 April 2015
Delivered to the ISS aboard a Dragon cargo ship for studies to examine the effects of weightlessness on organisms where physical activity isn't an option.

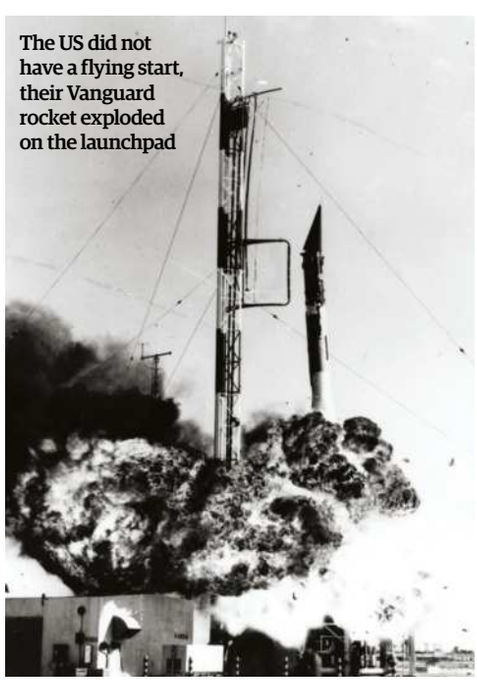
seen by human eyes. On 3 February 1966, a Soviet spacecraft, Luna 9, performed the first soft landing on another celestial body.

Russia also held the advantage in human space exploration, flying cosmonauts into orbit for several days, sending the first woman into space, launching the first multi-person spacecraft and executing the world's first spacewalk. However, the pendulum shifted in the mid-1960s, and America took the lead, flying longer missions, performing spacewalks and docking with other spacecraft. Its investment in Kennedy's goal peaked at five per cent of the federal budget. Meanwhile, the Soviets suffered the premature death of their chief rocket designer, Sergei Korolev, and the advantage slipped from their fingers. Yet the dangers of space exploration were ever-present. America lost three Apollo astronauts in a launchpad fire in January 1967 and, just three months later, a Russian cosmonaut plunged to his death when the parachutes on his descending Soyuz spacecraft failed to open.

In spite of the emphasis on reaching the Moon, both nations also turned their attention further afield, with the United States completing the first flyby of Mars with Mariner 4 in July 1965. The spacecraft's photographs revealed a hostile world, with no evidence of wind or water erosion, and a virtual absence of a magnetic field. Soviet missions to the Red Planet were more troubled: three exploded during launch, and another was lost during its outward journey. Mariner 2 flew past Venus in December 1962, while Russia's Venera 3 was first to crash-land on the planet's surface in March 1966. A year later, Venera 4 became the first spacecraft to take direct measurements from another planet's atmosphere, revealing carbon dioxide as Venus' main constituent.

The race to the Moon continued unabated. In November 1967, America test-flew its Saturn V lunar rocket for the first time, and the following September, Russia launched the Zond 5 spacecraft around the Moon, carrying a payload which included mealworms, wine flies, plants and a pair of tortoises. They became the first living creatures to venture into deep space, visit our closest celestial neighbour and return safely to Earth.

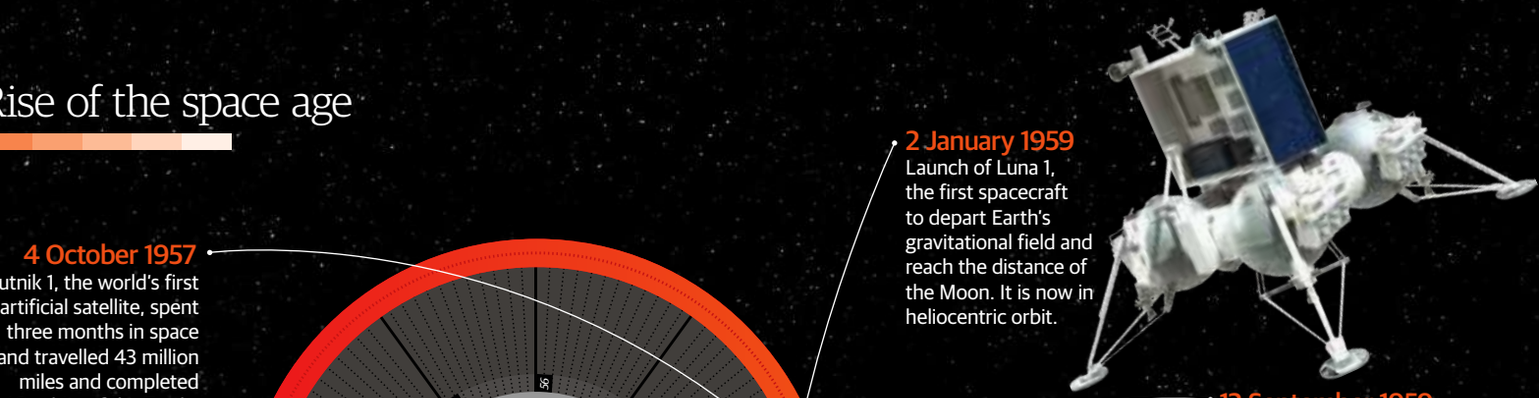
As the end of the decade approached and the final lap of the space race began, CIA intelligence



The US did not have a flying start, their Vanguard rocket exploded on the launchpad

Space Age Timeline

The US and Russia pressured each other into great advances



4 October 1957
Sputnik 1, the world's first artificial satellite, spent three months in space and travelled 43 million miles and completed 1,440 orbits of the Earth.

3 November 1957
Launch of the dog Laika, the first living creature to enter orbit around the Earth. She died within hours, when the cabin of her Sputnik 2 satellite overheated.

2 January 1959
Launch of Luna 1, the first spacecraft to depart Earth's gravitational field and reach the distance of the Moon. It is now in heliocentric orbit.

12 September 1959
Luna 2 became the first spacecraft to physically impact the Moon, crash-landing in the Mare Imbrium region, close to the craters Aristides, Archimedes and Autolycus.

7 October 1959
Never before seen by human eyes, the lunar far side, as seen for the first time by Luna 3, proved to be mountainous, with very few low-lying plains.



12 April 1961
Atop a modified version of Sergei Korolev's R-7 intercontinental ballistic missile, Yuri Gagarin became the first human being to enter space and complete a single Earth orbit.

20 February 1962
John Glenn became the first American to orbit the Earth, launching aboard a modified Atlas intercontinental ballistic missile and returning to a splashdown in the Atlantic Ocean.

5 May 1961
Three weeks after Gagarin's triumph, Alan Shepard became America's first man in space. He flew a 15-minute suborbital voyage aboard the Freedom 7 capsule.



14 December 1962
Mariner 2 became the first spacecraft to successfully encounter another planet when it flew within 18,700 miles of Venus, revealing thick atmospheric clouds.

16 June 1963
Former factory worker Valentina Tereshkova was hurriedly trained as part of a propaganda campaign by the Soviet Union to secure a record for the first woman in space.

18 March 1965
For 16 minutes, Alexey Leonov floated in the vacuum of space, protected only by his pressurised suit. In doing so, he became the world's first spacewalker.

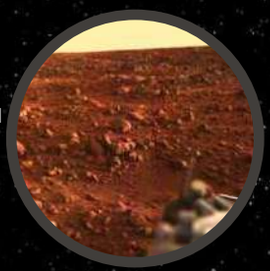
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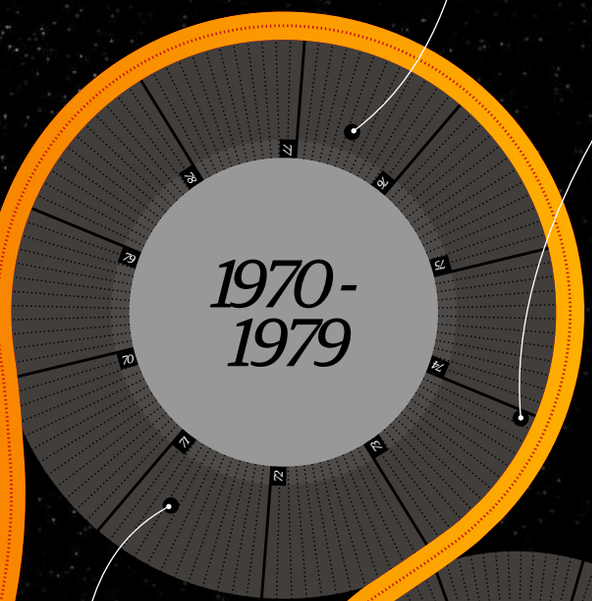
20 July 1969
After millennia of gazing upward at the Moon, the space race officially ended when Neil Armstrong and Buzz Aldrin triumphantly set foot on the Sea of Tranquility.

24 December 1968
On Christmas Eve 1968, Apollo 8 astronauts Frank Borman, Jim Lovell and Bill Anders observed 'Earthrise' from behind the limb of the Moon, for the first time.

20 July 1976
Seven years after the first manned Moon landing, Viking 1 became the first spacecraft to soft-land on the surface of Mars and successfully completed its mission.

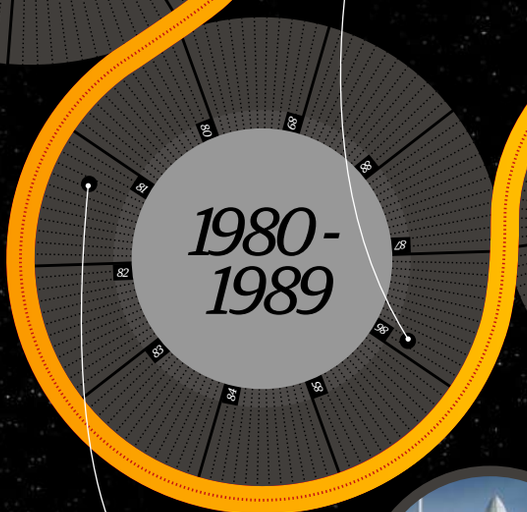


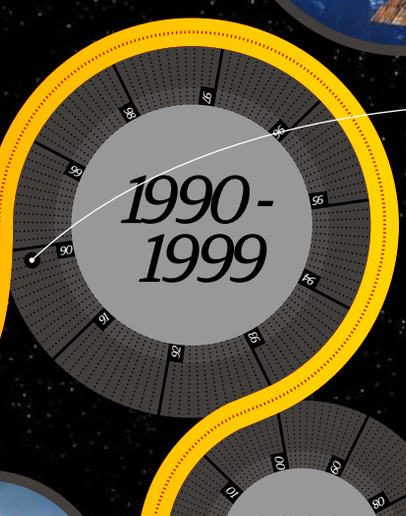
3 December 1973
Pioneer 10 became the first spacecraft to cross the asteroid belt and fly past Jupiter. It revealed the giant planet's punishing radiation belts, which caused several transistors to fail.



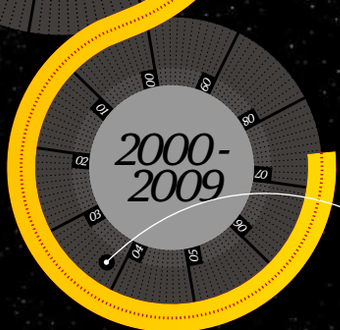
20 February 1986
Unlike previous 'monolithic' space stations, Russia's Mir complex was intended to be evolvable, with add-on modules. It remained in space for 15 years.

19 April 1971
Defeated in the race to the Moon, the Soviets turned their attention to near-Earth projects. They became the first nation to launch a long-duration space station, Salyut 1.





14 February 1990
From the very edge of the Solar System, Voyager 1 acquired a 'family portrait', showing six of the then-known planets, minus Mercury, Mars and the dwarf planet Pluto.





15 October 2003
Taikonaut Yang Liwei became the first Chinese spacefarer when China launched the Shenzhou 5 spacecraft, and became the third nation to launch its own personnel into orbit.

15 July 1965
Mariner 4 became the first spacecraft to successfully observe Mars, returning the first-ever images from deep space. It revealed the planet as cratered and geologically dead.



12 April 1981
STS-1, maiden voyage of Columbia, represented the first flight of a reusable winged orbital spacecraft with humans aboard. It marked the dawn of a 135-flight career for the shuttle fleet.

hinted a large Soviet rocket, the N-1, was undergoing final preparations to send a pair of cosmonauts around the Moon. Reconnaissance satellite imagery showed the rocket on its launchpad and, in August 1968, America hurriedly moved to upgrade Apollo 8 from an Earth-orbital flight to a lunar voyage. In just four months, the mission rose from the drawing board to reality, and astronauts Frank Borman, Jim Lovell and Bill Anders became the first men from Earth to settle into orbit around the Moon.

The N-1, meanwhile, suffered two catastrophic failures in February and July 1969, eliminating the last remaining Soviet hope of somehow getting cosmonauts onto the lunar surface before Neil Armstrong and Buzz Aldrin. Another unmanned spacecraft, Luna 15, sought to tame the impending American triumph by bringing some lunar soil back to Earth, but it ignominiously crashed into the Moon a few hours after Armstrong and Aldrin landed at the Sea of Tranquility.

With the space race 'won', political attitudes changed. The Soviets refocused their attention on building long-term space stations in Earth orbit, while America developed the shuttle as a more cost-effective means of reaching space.

Eventually, the two former foes united their efforts in today's International Space Station. And aboard that station on the 60th anniversary of Sputnik 1's success, astronaut Joe Acaba was filled with wonder for the past and excited hope for the future. "Amazing to be on Space Station and reflect on how far we've come," he tweeted. "What will the next 60 years bring us?"





The success of Vostok 1 was an enormous propaganda victory for the Soviets, forever immortalising the cosmonaut, Yuri Gagarin

The FIRST MAN in SPACE

After a stellar start to the space race, the Soviet Vostok programme dealt the US a crushing blow

★ Written by Hareth Al Bustani ★

By the late-1950s, having kicked off the Space Race by launching the shiny metal satellite Sputnik into Earth's orbit, the USSR went on to develop the first spacecraft to land on the Moon and send the first animal into orbit. With these successive victories over the US space programme, the Soviets gained legitimate ground to claim technological supremacy on the world stage.

However, while dogs and metal were one thing, the Americans were not long behind, and there was still one great defining breakthrough that neither country had yet managed to accomplish – one that would capture imaginations and thrust humans into a new epoch – sending a person into space.

The Soviets began developing systems for a manned orbital satellite in 1958. The project was led by Mikhail Tikhonravov, who had worked on rocket design and space exploration with Sergei Korolev since 1933, and chief conceptual designer Konstantin Feoktistov, a stubborn and brilliant scientist who hoped to one day visit space himself.

In April 1959 the team drew up a secret draft plan of a spacecraft capable of carrying man into space, followed the next month by ballistic calculations with orbital descent options. The army gave them access to firing ranges, military specialists, troops and, crucially, the newly updated R-7A rocket – with an added third stage capable of launching a payload of five tonnes into near-Earth orbit.

While the Americans had successfully developed the Discoverer espionage satellite which would later carry cameras and film, the Soviets still lacked the technology to bring vessels back to Earth – something that was imperative for a manned mission. To speed things along, Premier Khrushchev tasked the Experimental Design Bureau OKB-1 with developing a satellite for reconnaissance and navigation alongside a "sputnik for human flight".

After some heated debates, Korolev signed off on a ballistic landing configuration with a spherical descent module, equipped with a thermal shield. An instrument aggregate compartment housing

YURI GAGARIN

HOW THE WORLD'S FIRST COSMONAUT ROSE FROM AN OBSCURE FARM TO SPACE

Yuri Alekseyevich Gagarin was born in 1934 in the village of Klushino, near Gzhatsk, a region of around 10,000 people in the heart of central Russia. His parents Aleksey and Anna were peasants, members of a collective farm, growing grain and flax.

His early life was a traditional one, growing up in a log hut with a thatched roof, set amidst fields and forests. However, Yuri's world was turned upside down when Nazi Panzer units overran the village in 1941. A Nazi officer took over the Gagarin residence during the last years of occupation.

After the war, the Gagarins moved to Gzhatsk, where Aleksey worked as a carpenter, Anna tended the fields and Yuri continued his secondary education – joining the Young Communist League in 1949. He later moved to Lyubertsy, an industrial suburb of Moscow, where he fell in love with volleyball, basketball and, most importantly, aeronautics and space – never missing an airshow at the nearby Tushino Airfield.

Having graduated from vocational school as a moulder with distinction, he enrolled at an industrial college in Saratov, joining the Saratov Aero Club. After completing his studies he enlisted at a Soviet Air Force training centre, graduating in 1957 with top honours. While there he met the love of his life, Valentina, with whom he would later have two children.

The 27-year-old Yuri Gagarin emerged from the Vostok mission, not just one of 1,200 Gagarins living in Moscow, but a living legend. As Khrushchev would tell him: "You have made yourself immortal, because you are the first to penetrate into space." Named a Hero of the Soviet Union by a smooching Khrushchev, monuments of Yuri were erected across the country and streets were named in his honour.

Training future space cadets, he quickly rose up in the Communist party, chairing the Soviet-Cuban Friendship Society, attending the 22nd Congress of the Communist Party and becoming deputy in the Supreme Soviet.

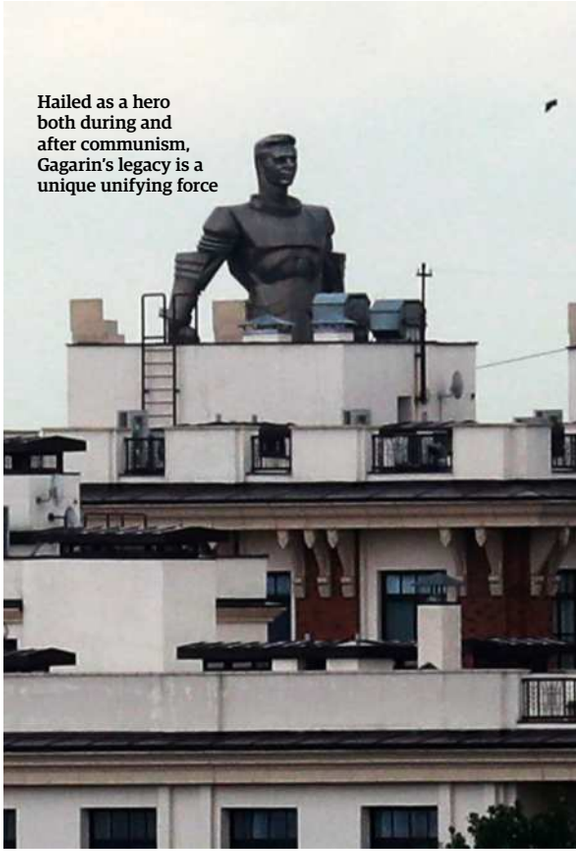
Unfortunately, in 1968, having reached a colonel's rank, Gagarin died test piloting a new aircraft; a devastatingly pedestrian death for one of the USSR's most beloved heroes. Despite his untimely demise, the cosmonaut's reputation outlived that of even the Communist regime. As one writer put it: "When perestroika started and all the heroes of the previous years had been shattered to dust, the only remaining, real, tangible hero was Gagarin; the first man in space, and a good guy whom both the elderly and the young trusted."



Of the 250 candidates brought in for testing, Yuri Gagarin was among the space programme's 'Vanguard Six'



Vostok 1's R-7A rocket was capable of launching a payload of five tonnes into near-Earth orbit



Hailed as a hero both during and after communism, Gagarin's legacy is a unique unifying force

disposable hardware would simply break off before entering the atmosphere.

As the US continued developing its own Atlas missile, capable of carrying over 1.3 tonnes into orbit, the pressure was on – failure at this critical juncture would completely undermine the Soviets' cumulative propaganda victories. With the Americans planning to fly the first manned suborbital Mercury mission in 1961, a Soviet document – On a Plan for the Mastery of Cosmic Space – required all testing to be completed by the end of the year.

By now the project had a name: Vostok, or 'East'. Comprising of three vessels – 1K, 2K and 3KA – the first was a reconnaissance satellite, and the third the actual piloted spacecraft. The policy governing the programme required all assemblies, instruments and systems to be tested and certified 'Suitable for 3KA'. The military carried out thorough checks, with chief designers and section heads personally liable for their components, ushering in a new age of quality and consistency for the Soviet space programme.

One early Vostok mission, Korabl-Sputnik 2, carried an assortment of lifeforms into orbit, notably the dogs Belka and Strekla, becoming the first to bring animals back to Earth safely. However, Korolev was concerned that Belka had clearly become distressed during the fourth orbit, and had vomited due to weightlessness. As a result, he decided to restrict his manned mission to no more than one orbit, with the ship controlled automatically from the ground and a manual override code handed to the pilot in a sealed envelope – just in case.

Returning to Earth, the braking rocket engine would need to fire its thrust in the opposite direction from the craft's orbital velocity vector. Once the braking burn had been applied, the spacecraft would execute a braking turn – the atmosphere slamming the brakes on the remaining energy. The craft would communicate with Earth via a variety of radio links, along with the capacity to broadcast TV from space.

As the project grew increasingly complex, so too did the bureaucracy of OKB-1, as the Council of Chief Designers watched their power dissipate among designers and organisations representing different disciplines. Though the Council of Six remained, Korolev had to bring in 15 new voting members, representing a variety of bodies from the Institute of Aviation Medicine to Air Force Command. Korolev succeeded in establishing himself atop this new hierarchy – named the rocket-space complex – delegating to his deputies, who in turn worked with their relevant chief designers. While the old guard did their best to mitigate risk, young engineers threw caution to the wind, creating a healthy balance of ambition and control.

In 1960, only two of five Korabl-Sputnik launches went into orbit and made it back. With a 'soft landing' system still years away, the only way of ensuring a safe landing for the astronaut was a two-step landing system, which ejected the cosmonaut out of the descent module with a parachute. The following year, two further missions carried animals and mannequins into space, safely ejecting the dummy, 'Ivan Ivanovich'.

After sifting through 3,000 pilots' records, the team initially brought in 250 prospective candidates. This number was slowly whittled away by medical examinations, vigorous rotating chair training for weightlessness and ten-day isolation chambers. Of the 12 candidates selected by the Air Force to enter the Cosmonauts Training Center, the six most promising were dubbed the 'Vanguard Six'. Among them was a young man called Yuri Gagarin, who persevered through the intense training and the Vostok simulator, TDK-1, the first of its kind in the USSR.

Finally, in March 1961, Korolev recommended the launch of a Vostok spacecraft with a human aboard, approved the next month. Gagarin was selected to pilot the vehicle, with Gherman Titov his backup.



Though the Vostok spacecraft was controlled from the ground, a team member secretly informed Gagarin of the override code in advance



The Vostok programme ushered in a new era of efficiency, centred on the Baikonur Cosmodrome

12 April was an auspicious day, marked by a clear, sunny sky over the top-secret launch site in Baikonur, Kazakhstan. Yuri Gagarin embraced his comrades and stepped onto the elevator before entering the descent module. When technicians discovered the hatch was not sealed properly, they had to spend an hour resealing it, during which time Gagarin asked for music to be played over the radio.

Leaning back into his foam-padded ejection seat, he yelled, "Off we go," and away Vostok went. Two minutes later the four strap-on boosters ran out of propellant and fell away, and minutes later the rocket core stage followed suit. As the craft soared into space, Gagarin beamed through the radio: "Visibility is excellent! Out the window I see Earth, clouds, I see rivers. It's beautiful."

His spherical cabin featured three portholes, a life-support system, radios and various instrumentation. An attached service module housed batteries, orientation rockets, a retro system and other equipment. Having completed a single orbit and travelling 27,359 kilometres (17,000 miles) per hour, the service module detached and the descent module returned to Earth, with Gagarin ejecting safely. Despite some hiccups along the way, such as a brief detachment scare, the Soviets had done it.

After landing, Gagarin, clad in an orange suit with a white helmet, encountered a farmer and his daughter. "When they saw me in my spacesuit, and the parachute dragging alongside as I walked, they started to back away in fear. I told them, 'Don't be afraid. I am a Soviet like you, who has descended from space, and I must find a telephone to call Moscow!'"

The psychological impact on both the US and USSR was profound – the Soviets emerged the masters of space and technology, and with the US 25 days away from suborbital flight, they would have to set themselves a profoundly ambitious task to return from a defeat of this magnitude.

REACTIONS TO VOSTOK

THE VOSTOK SUCCESS ELICITED POWERFUL REACTIONS OF JOY AND FEAR ACROSS THE WORLD

Thousands paraded across Moscow, chanting 'cosmonaut' to rousing music blasted from loudspeakers. The celebrations continued across the country, as Khrushchev gloated to Gagarin: "Let the capitalist countries try to catch up with our country, which has blazed a trail into space and which has launched the world's first cosmonaut."

Indian Prime Minister Jawaharlal Nehru congratulated the USSR on "a great human victory of man over the forces of nature". Indonesia, meanwhile, said it marked "an entirely new era in human life", hoping it would "have only a beneficial influence on mankind".

Yomiuri newspaper in Tokyo noted that "real competition" was "just beginning", but encouraged the US and USSR to "use their new knowledge and techniques for the good of mankind".

Despite the humiliating blow, President Kennedy extended the Soviet scientists and engineers a cordial congratulations: "It is my sincere desire that in the continuing quest for knowledge of outer space, our nations can work together to obtain the greatest benefit to mankind."

While Wernher von Braun celebrated the "remarkable" achievement, the 'father' of the hydrogen bomb, Edward Teller, said the USA's failure to put a man in space first was the result of "years of unimaginative, materialistic thinking".

The German daily, *Die Welt*, said the USSR was now reaping "the benefits of its purposeful efforts", adding: "It could have been avoided. For weeks the Americans had at their disposal the technical know-how required to send a man into space and get him back."

The Vostok mission captured the imagination of the world, a potent symbol of socialism's success



Meanwhile, the director of the School of Physical Sciences at the Australian National University dismissed the mission as "just a stunt", compared to previous accomplishments.

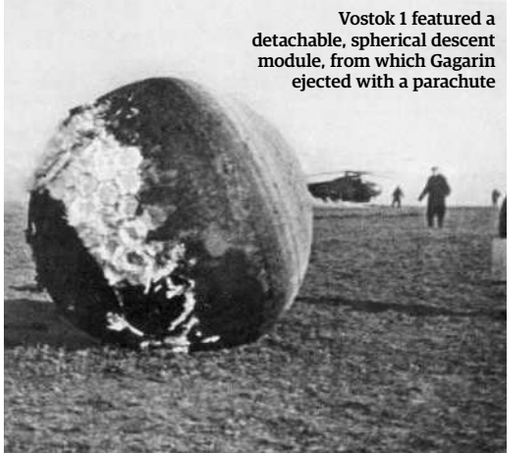
© Getty Images, Alamy



Vostok's success was a source of pride for Soviet citizens, who considered it a victory of socialism over capitalism



In the lead-up to Vostok, the Korabl-Sputnik 4 and 5 missions successfully carried the dogs Chernushka and Zvezdochka into orbit, and brought them home safely



Vostok 1 featured a detachable, spherical descent module, from which Gagarin ejected with a parachute



Khrushchev celebrates alongside Gagarin, right, and Gherman Titov, the backup pilot for Vostok 1, who went on to become the second man in orbit



The crew of Apollo 7 posing for an official portrait in their suits



How the first successful test of both spacecraft and crew paved the way to the Moon

APOLLO 7

"We have lift-off"

Reported by Elizabeth Howell

© NASA JSC

Apollo 7

Apollo 7 was the programme's first successful crewed flight into space. The crew of Wally Schirra, Don Eisele and Walter Cunningham spent nearly 11 days in space as they orbited Earth and tested out the spacecraft that was designed to bring humans safely to the Moon and back again.

By the time the mission launched on 11 October 1968, NASA had worked hard at improving crew safety and heeded the concerns that arose after a Command Module fire killed the Apollo 1 crew 20 months earlier during a routine launch pad test. But Apollo 7 proved to be an engineering success, despite crew illness and reports of tension between the space crew and ground crew.

Apollo 7 was essentially a test flight for manned spacecraft. After Apollo 1, three unmanned launches – designated Apollo 4, 5 and 6 – had tested the Saturn rockets, the Lunar Module and the Command Module. No missions or flights were ever designated Apollo 2 or 3.

Commanding the Apollo 7 crew was Wally Schirra, a veteran of NASA's Mercury programme, which was the first human spaceflight programme at NASA. Schirra was the fifth American in space and flew a mission called Sigma 7 on 3 October 1962, circling six times around the Earth. Schirra was also part of the Gemini programme that had two crews of two people fly into space simultaneously. He commanded the Gemini 6

The crew



Below:
The crew of Apollo 7, pictured following their return to Earth. From left to right: Commander Walter Schirra, Command Module pilot Donn Eisele, and Lunar Module pilot Walter Cunningham





Left: The expended Saturn IVB stage as photographed from the Apollo 7 spacecraft during transposition and docking manoeuvres. The round, white disc is a simulated docking target similar to that used on the Lunar Module

Left below: Apollo 7 launched from the Kennedy Space Center on 11 October 1968

"The crew struggled to perform their tasks during the 11 days of space travel"



© All images: NASA JSC

mission, which (along with Gemini 7) performed the first rendezvous between two manned spacecraft. Schirra was the only astronaut who flew in the Mercury, Gemini and Apollo programmes.

With Schirra were two spaceflight rookies. Walter Cunningham was a Navy pilot, who previously to joining NASA, had worked on classified defence studies as a scientist for the Rand Corporation. Meanwhile, Donn Eisele was an Air Force test pilot who had previously worked on special weapons development projects.

'Yabba Dabba Doo'

After they had completed a couple of Earth orbits, Schirra turned the Command Module around to simulate a docking with the third stage of the Saturn IB rocket, called Saturn IVB. Future Moon missions would require dockings between two spacecraft, the command and Lunar Modules, so the manoeuvre was important practice.

The crew also tested out the Command Module engine extensively. This engine had to work flawlessly for the upcoming Moon missions. It was designed to bring crews to the Moon, slow the spacecraft down to enter lunar orbit, speed the spacecraft up to exit lunar orbit, and then position the crew for a safe re-entry back to Earth.

In NASA parlance, the engine had eight "nearly perfect firings" in the eight times the crew turned it on and off. The engine gave a powerful jolt to the spacecraft the first time it fired, slightly startling the crew. Schirra, feeling the vibration, yelled "Yabba Dabba Doo!" This was the catchphrase for Fred Flintstone, a popular cartoon character from the animated 1960s sitcom *The Flintstones*.

While the mission in large part was a success, there were a few engineering glitches aboard the Command Module. The windows fogged, making visibility poor (but not impossible) for the astronauts inside. Also, there were minor problems

Main: After the tragic Apollo 1 fire, over 1,300 modifications were made to the Apollo spacecraft to improve safety



© NASA/JSC

in the electrical and fuel cell systems, and – in the crew's opinion – overly noisy cooling fans inside the cabin. All of these issues were noted so they could be fixed prior to future missions.

Controversial crew performance

An Apollo spacecraft was cramped quarters under the best of circumstances. On Apollo 7, the crew immediately learned of one of the drawbacks: it was very easy to catch an illness.

Schirra came down with a cold only 15 hours after launch, according to NASA, and passed along the illness to Cunningham and Eisele. Accounts differ on the severity of their colds.

In the microgravity environment of space, fluids don't drain as they do on Earth. This meant blocked ears and noses for the crew, who tried – with little success – to alleviate the symptoms by taking medication. The crew struggled to perform their tasks during the 11 days of space travel. Biographical accounts from astronauts and mission controllers affiliated with Apollo 7 said the crew was frequently cranky when talking to ground controllers. However, the description varies depending on who's telling the story.

Multiple biographies say that Schirra became so frustrated he pulled the plug on one of the television broadcasts. Eisele also complained about one test the crew performed, saying he wanted to speak to the person who "thought up that little gem". That person turned out to be a high-ranking NASA official: respected Mission Control flight director Glynn Lunney.

Just before re-entry, the crew elected not to wear their suit helmets; they were concerned about pressure hurting their ears as they arrived on Earth, and wanted the chance to blow their noses to relieve the pressure. This drew the ire of some at NASA. "It was insubordinate [...] This crew shouldn't fly again," wrote flight director Christopher Kraft in his 2001 memoir, *Flight: My Life in Mission Control*.

In his own 2000 biography, *Schirra's Space*, Schirra said the disagreements between flight crew and ground crew boiled down to one thing: "I was convinced that the men in Houston were overlooking certain intangible things," he wrote. While not elaborating on what those things were, he added that the crew had worked with the spacecraft for three years and knew its capabilities.

Conflict aside, the Apollo 7 mission was an engineering success. The programme was ready to move on to the next phase: targeting the Moon.

Apollo 7 legacy

The current location of the Apollo 7 spacecraft is at the Frontiers of Flight Museum in Dallas, where Cunningham was a long-standing board member. 2018 marked the 50th anniversary of Apollo 7.

While Apollo 7 is not as well-remembered as other Apollo missions that reached the Moon, it was an essential engineering test to prove the performance of the Command Module. NASA's next mission, Apollo 8, sent three astronauts in a Command Module directly to the Moon for a lunar-orbiting mission. It was a daring mission that would have been far riskier without the Apollo 7 tests.





Top: Walter Cunningham pictured aboard Apollo 7. The relatively long mission and cramped conditions of the capsule led to some tensions between the crew and Mission Control

Middle: The crew's view of the sunrise over the Gulf of Mexico, taken during the spacecraft's 134th orbit of the Earth



Left: The crew held the first live television broadcast from space during their mission



APOLLO 11
THE INSIDE STORY

What *really* happened the day we landed on the Moon

Written by Nick Howes

It's hard for many today to comprehend that almost 50 years ago, humankind achieved one of the greatest technological feats of all time. Less than nine years after President Kennedy had set the goal of landing a man on the surface of the Moon and returning him safely to Earth, NASA achieved that most astonishing aim on 20 July 1969.

Those intervening years had been a white-knuckle ride. Beginning with Alan Shepard's 15-minute suborbital Mercury flight in 1961, NASA progressed through a series of milestones in their mission to reach the Moon. There was the loss of a Mercury capsule and the near-drowning of its pilot Gus Grissom; John Glenn's re-entry with a retro-rocket still attached to his Friendship 7 capsule; a slew of hugely successful Gemini missions including one that almost span out of control, potentially threatening the life of the astronaut who in 1969 would take that first historic step; and then four fully flown Apollo missions, two in low Earth orbit, two that orbited the Moon and only one to test the full system. NASA had to endure the catastrophic loss of Grissom and his two crewmates, Edward White and Roger Chaffee in 1967 in Apollo 1's tragic fire on the launch pad, but the space agency had resolved to carry on, completely redesigning the lunar command module and carrying out major changes to the lunar landing module (the LEM as it was known) in that short space of time.

Amid triumph and tragedy, on 16 July 1969 NASA was ready to go to the Moon. Yet the trials and tribulations of the previous years were not over and the three-man crew of Apollo 11 – Neil Armstrong, Buzz Aldrin and Michael Collins – were facing one of the most dramatic spaceflights in history.

We recall the historic first words said on the lunar surface, and the elation of the largest TV audience in history at that time when they saw those grainy black and white images from the Moon, but there is so much more to the story of Apollo 11 that may not be as well known.

Their first task, of course, was to leave Earth on top of the mighty Saturn V rocket – the tallest, most powerful rocket ever built. Many astronauts who were propelled into space by the Saturn V describe it as being a very smooth ride. Neil Armstrong is quoted as saying that while the launch for all those watching on Cocoa Beach or at Cape Canaveral was deafening, the crew could detect a slight increase in background noise, a lot of shaking, and feeling akin to being onboard a large jet aeroplane on take-off. Yet as smooth a ride as it was, being on top of that much rocket fuel was always a dangerous experience.

"A space mission will never be routine because you're putting three humans on top of an enormous amount of high explosive," Gene Kranz, flight director for Apollo 11's lunar landing, told us. If there were any nerves, the astronauts weren't feeling it, according to Buzz Aldrin. "We felt that our survival was in the probability of 99 per cent. There were a lot of risks involved but there were a lot of points to abort the mission short of continuing on something risky."

Once in space, the command service module had to rotate and dock with the lunar module, which was



Armstrong waves to well-wishers in the Manned Spacecraft Operations Building as he, Collins and Aldrin prepare to be transported to Launch Complex 39A



This iconic picture shows astronaut Buzz Aldrin's bootprint in the lunar soil

"A space mission will never be routine... you're putting three humans on top of an enormous amount of high explosive" **Gene Kranz**

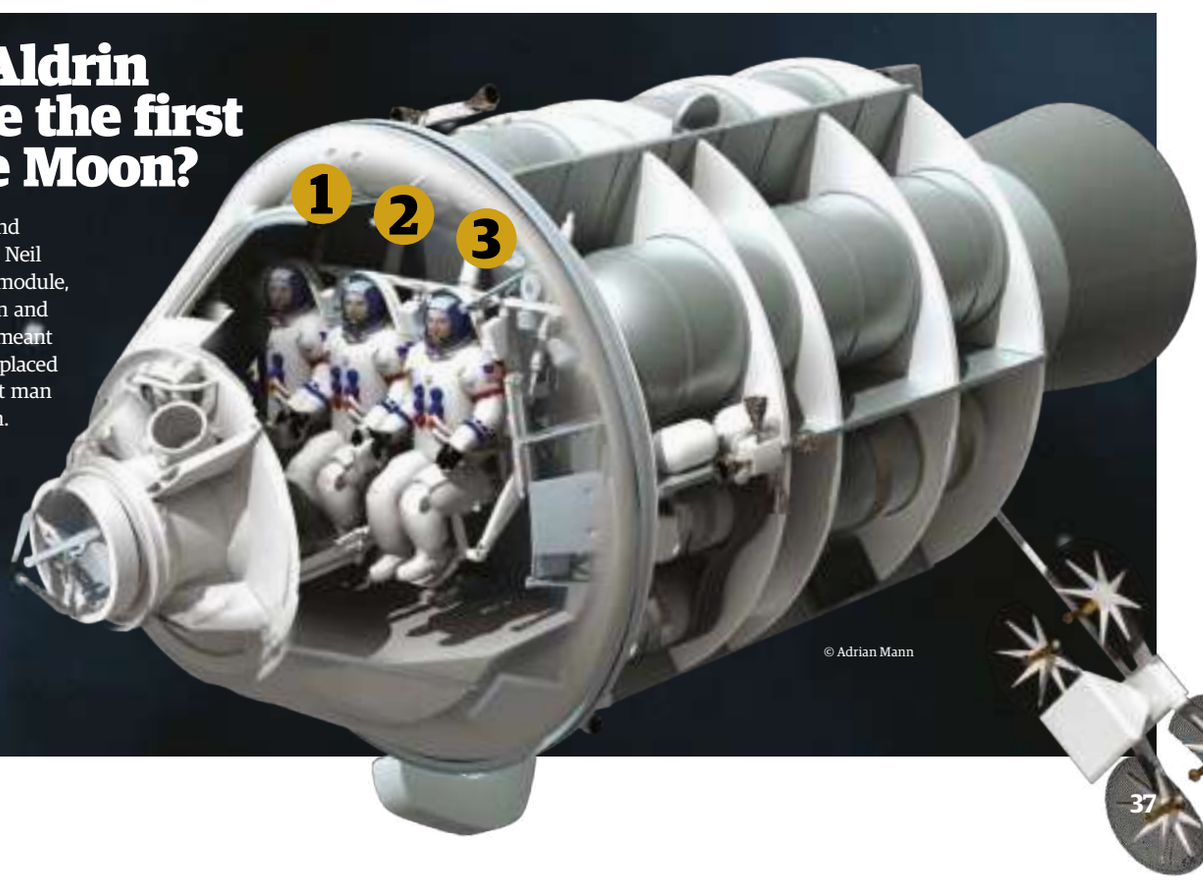
Was Buzz Aldrin meant to be the first man on the Moon?

The seating plan in the command module. When Buzz Aldrin and Neil Armstrong moved to the lunar module, it's thought that the seating plan and the position of the entry hatch meant that Neil Armstrong was better placed to exit first and become the first man on the Moon, rather than Aldrin.

1 Michael Collins (command module pilot)

2 Buzz Aldrin (lunar module pilot)

3 Neil Armstrong (commander)



© Adrian Mann

BUZZ ALDRIN

"Somebody said that [me not taking pictures of Neil] was intentional"

After returning to Earth, hardly any shots of the first man on the Moon led Buzz Aldrin to be questioned

It's said that Aldrin was getting Armstrong back by taking no photos of him on the Moon in retribution for the latter getting the honour of being the first to set foot on the Moon. However, and according to Aldrin, he was about to take a picture of Armstrong at the flag ceremony when President Nixon called, distracting them from the task. "As the sequence of lunar operations evolved, Neil had the camera most of the time, and the majority of the pictures taken on the Moon that include an astronaut are of me," Aldrin states. "It wasn't until we were back on Earth and in the Lunar Receiving Laboratory looking over the pictures that we realised there were few pictures of Neil. My fault perhaps, but we had never simulated this during our training."

Before his death in 2012, Armstrong defended Aldrin, stating: "We didn't spend any time worrying about who took what pictures. It didn't occur to me that it made any difference, as long as they were good... I don't think Buzz had any reason to take my picture, and it never occurred to me that he should."

"When I got back and someone said, 'There's not any of Neil,' I thought, 'What in the hell can I do now?' I felt so bad about that," says Aldrin. "And then to have somebody say that might have been intentional... How do you come up with a nonconfrontational argument against that?"



Buzz

Buzz Aldrin moves toward a position to deploy two components of the Early Apollo Scientific Experiments Package (EASEP) on the surface of the Moon during the Apollo 11 extravehicular activity



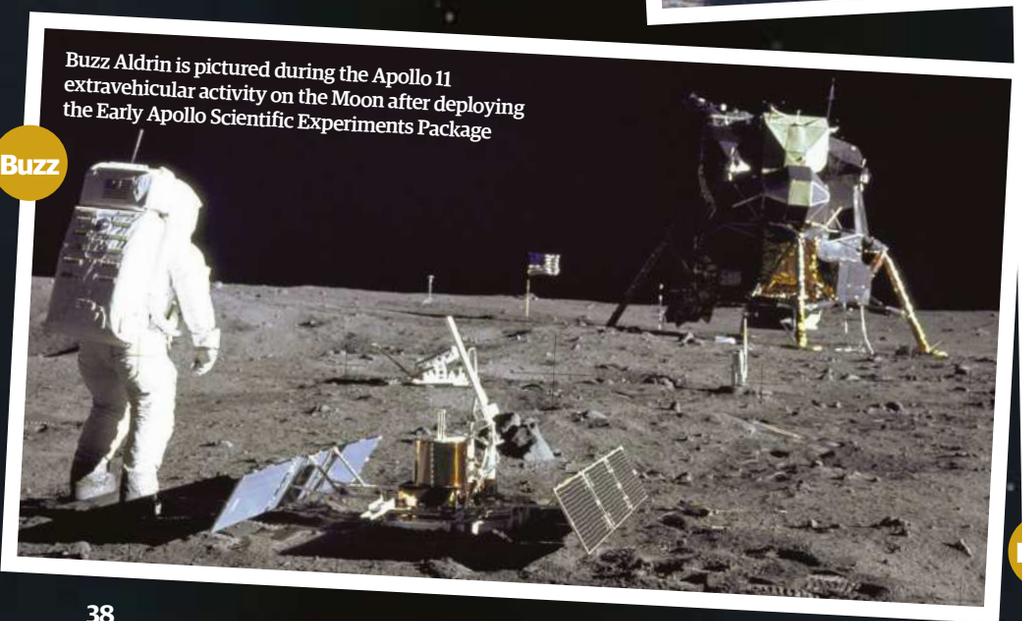
Buzz

The lunar module pilot poses for a photograph beside the deployed United States flag during an Apollo 11 extravehicular activity (EVA) on the lunar surface



Neil

Neil Armstrong works at the lunar module in the only photo taken of him on the Moon from the surface



Buzz

Buzz Aldrin is pictured during the Apollo 11 extravehicular activity on the Moon after deploying the Early Apollo Scientific Experiments Package



Buzz

Buzz Aldrin walks on the surface of the Moon near the lunar module during the Apollo 11 mission

embedded in the final S-IVB stage of the Saturn V rocket. After the two spacecraft had mated, onwards they flew to the Moon, leaving the S-IVB stage trailing in space behind them.

Later, the crew spotted something strange outside. A light that appeared to be following them. When Michael Collins used the onboard telescope to view it, he couldn't make it out – it looked like a series of ellipses but, when focusing the telescope, it seemed L-shaped, but that could have just been the way sunlight was glinting off it.

Reticent to tell mission control in Houston, Texas, that they were being raced to the Moon by a UFO, the crew cautiously asked where the S-IVB rocket stage was. "A few moments later they came back to us and said it was around 6,000 miles away," recalled Aldrin. "We really didn't think we were looking at something that far away, so we decided to go to sleep and not talk about it any more."

Aldrin doesn't believe it was an alien spaceship, but that it was more likely the Sun reflecting off one of four metal panels that fell away from the rocket stage when they docked with the lunar module.

For almost four days, Apollo 11 flew towards the Moon, where Armstrong and Aldrin climbed into the lunar module – the Eagle – and said goodbye to Collins, who was to remain in the command module in orbit around the Moon.

As the Eagle flew around the far side of the Moon, things in mission control were growing tense. "There was a degree of seriousness in mission control that I hadn't even seen in training," said Kranz. "That was when you realised this was the real deal: today, we land on the Moon."

"There was a degree of seriousness in mission control that I hadn't even seen in training" **Gene Kranz**



The flight controllers erupt into applause as Apollo 11 splashes down in the Pacific Ocean on 24 July 1969, successfully completing the mission



The huge, 363-feet tall Saturn V rocket carries three men towards the Moon from Pad A, Launch Complex 39, Kennedy Space Center on 16 July 1969



After a rehearsal mishap when the Lunar Landing Research Vehicle exploded, Neil Armstrong floats safely to the ground

Almost immediately after separating from the command module, there were problems. Radio communication with the Eagle was sketchy at best and they were coming up to the point of no return, where the landing could no longer be aborted if something was wrong.

"It was up to me to decide if we had enough information to make the go/no-go [decision] and continue the descent to the Moon," said Kranz. So, five minutes before the powered descent to the lunar surface was due to begin, with radio communication cutting in and out, Kranz asked his flight controllers to give him their go/no-go based on the last frame of data that they saw. They all said "go." And then things turned from bad to nearly catastrophic.

The spacecraft's guidance computer, developed at MIT under the auspices of Charles Draper (the lab at MIT now bears his name) was a 2MHz system that was the first in the world to use integrated circuits. Its fixed memory was an ingeniously designed 'Core Rope', which consisted of a set of small hoops that 'Little Old Ladies' (as it was referred to at the time) along with machines would thread the code either through or around the hoops to give the computer its 1 or 0 value. If the MIT code was threaded incorrectly, the 'programmer' would have to laboriously go through the woven cores and debug it.

When the crew were approaching the Moon for the landing, various alarms were triggered by the computer. "Whatever information we were looking at [disappeared] and instead it gave us the code number of the alarm," said Aldrin. "It was disturbing and distracting and we didn't know what it meant."

The 1201 and 1202 alarms were obscure codes (and in effect the same error) that flashed up as Armstrong manually attempted to bring the lunar module down. Nobody seemed to know what the codes meant, except for two men: Jack Garman, a NASA computer engineer who had come across the codes before during a practice run, and Steve Bales, who was the Apollo guidance officer. The alarms were being caused by a problem with the landing radar that was stealing precious computing cycles, and the throttle control algorithm was barely working. The computer's 72kb of memory, barely enough to write a sentence in a modern word processor, was struggling as commands into it overflowed. Garman knew that it was safe to continue and allow the computer to handle matters. Its priority scheduling routines, which have formed some of the basis of a lot of modern code, were dumping lower priority tasks in favour of the ones critical to the lunar landing.

As the Eagle lander approached the surface on automatic, Armstrong and Aldrin realised that the scenery on the Moon's surface outside of the window didn't look familiar to them. "I think we may be a little long," commented Armstrong, referring to the Eagle having overshot its planned landing site. Looming ahead of them inside a crater was a dangerous-looking boulder field, and coming down on any of those giant rocks the size of houses would have damaged or perhaps even destroyed the Eagle. Armstrong took manual control, using the module's thrusters

APOLLO 11

One small step for [a] man, one giant leap for mankind



"Roger. Clock."
Neil Armstrong, Apollo 11 Commander



"Roger. Roll."
Bruce McCandless, CAPCOM



"Roger. We copy. We'll be configured and waiting for whatever you want to send down."
Bruce McCandless, CAPCOM



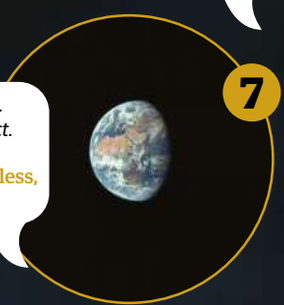
"Roger. 1 50."
Neil Armstrong, Apollo 11 Commander



"Apollo 11, Apollo 11, this is Houston broadcasting in the blind. Request OMNI Bravo."
Bruce McCandless, CAPCOM



"Roger. Oxygen heaters to AUTO, or you can watch them in the ON position, and oxygen fans manual ON."
Bruce McCandless, CAPCOM



"This is Houston. Readback correct. Out."
Bruce McCandless, CAPCOM



00:00:00 Liftoff

Stage I-powered flight

00:02:39 Stage I-powered cutoff

00:02:42 Stage II engine ignition

00:03:14 Launch escape tower jettison

Stage II-powered flight

00:08:56 Stage II-engines cutoff

00:08:56 Stage IV engine ignition

Stage IV-powered flight

00:11:23 Stage IV engine cutoff

01:35:08 Stage IV engine ignition

01:40:50 Stage IV engine cutoff

01:57:05 Command and service module guidance system separation and lunar module adapter, deployment of adapter panels and high-gain antenna

01:58:42 Command and service module guidance system 180-degree turnaround

02:41:40 Command and service module/Lunar module separation from stage IV

Navigation sightings

04:43:56 Service module ignition

04:44:04 Service module engine cutoff

1:52:11:45 Service module engine cutoff

46 hours
Systems status checks
Eat and sleep periods
Data transmit periods

199:23:26 Service module engine ignition

Command and service module guidance system reference alignment

200:16:26 Command and service module and service module separation

Communication blackout period

200,000 feet altitude

250,000 feet altitude

Heat shield and chute deployed at 24,000 feet

Deploy main chute at 10,000 feet

200:41:16 Touchdown in the Pacific Ocean

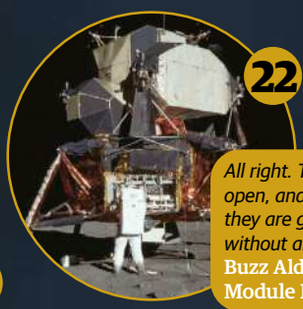
Ignition of Saturn V



"The Earth is really getting bigger up here and, of course, we see a crescent."
Michael Collins, Command Module Pilot



"Roger"
Charlie Duke, CAPCOM



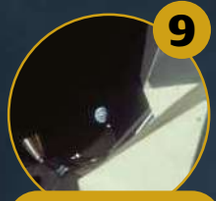
All right. The doors are open, and it looks like they are going to stay up without any problem.
Buzz Aldrin, Lunar Module Pilot



"Okay. You can make a Mark, Houston. *** deployed."
Neil Armstrong, Apollo 11 Commander



"This is too big an angle, Neil."
Buzz Aldrin, Lunar Module Pilot



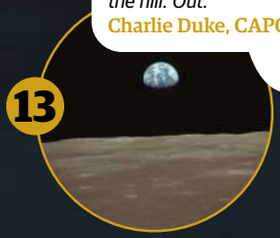
"Okay, no complaints. I was just curious as to what had happened."
Michael Collins, Command Module Pilot



"Okay."
Michael Collins, Command Module Pilot



"That's a good, reasonable way of describing it. It appears as though it made a difference just sitting back in the tunnel and gazing at all windows; it makes a difference which one you're looking out of. The camera right now is looking out the number five window, and it definitely gives a rosier or tanner tinge."
Buzz Aldrin, Lunar Module Pilot



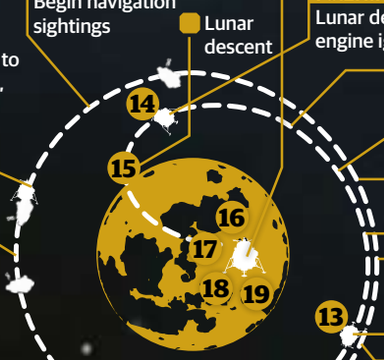
"Apollo 11, Houston. Thirty seconds to loss of signal. Both spacecraft looking good going over the hill. Out."
Charlie Duke, CAPCOM

"I think you've got a fine looking flying machine there, Eagle, despite the fact you're upside down."
Michael Collins, Command Module Pilot





"Apollo 11 is getting its first view of the landing approach. This time we are going over the Taruntius crater, and the pictures and maps brought back by Apollo 8 and 10 have given us a very good preview of what to look at here. It looks very much like the pictures, but like the difference between watching a real football game and watching it on TV. There's no substitute for actually being here."
Neil Armstrong, Apollo 11 Commander



46 hours
Systems status checks
Eat and sleep periods
Data transmit periods

51:40:59
Service module engine cutoff

9 hours
Systems status checks
Eat and sleep period
Data transmit period

51:40:51
Service module ignition

62:16:57
Service module engine ignition

62:17:01
Service module cutoff

64:04:38
Begin navigation sightings

66:17:43
Pilot transfer to lunar module, second orbit

Begin lunar module systems activation and checkout

Lunar descent

70:37:45
Lunar touchdown

70:27:17
Lunar descent engine ignition

Lunar module guidance system and reference alignment

69:29:03
Lunar module descent engine cutoff

Begin lunar orbit evaluation

Transfer orbit insertion

63:23:27
Service engine cutoff

Lunar orbit insertion

69:28:31
Lunar module descent engine ignition

69:05:32
Command and service module and lunar module separate on third orbit

66:45:53
Commander transfer to lunar module

"11, Houston. If that's not the Earth, we're in trouble."
Charlie Duke, CAPCOM



9 hours
Systems status checks
Eat and sleep period
Data transmit period

122:11:44
Service module engine ignition

28 hours
Systems status checks
Eat and sleep periods

1:52:11:44
Service module engine ignition

105:19:04
Liftoff

Lunar module ascent

Lunar module ignition

Midcourse corrections

Rendezvous manoeuvres

108:02:14
Command and service module and lunar module initial docking

109:00:04
Command and service module and lunar separate and lunar module jettison

Transfer crew and equipment from lunar module to Command and service module





"See you later."
Neil Armstrong, Apollo 11 Commander



"For those who haven't read the plaque... First there's two hemispheres, one showing each of the two hemispheres of the Earth. Underneath it says "Here Man from the planet Earth first set foot upon the Moon, July 1969 AD We came in peace for all mankind." It has the crew members' signatures and the signature of the President of the United States."
Neil Armstrong, Apollo 11 Commander

"Contingency sample is in the pocket. My oxygen is 81 percent. I have no flags, and I'm in minimum flow."
Neil Armstrong, Apollo 11 Commander

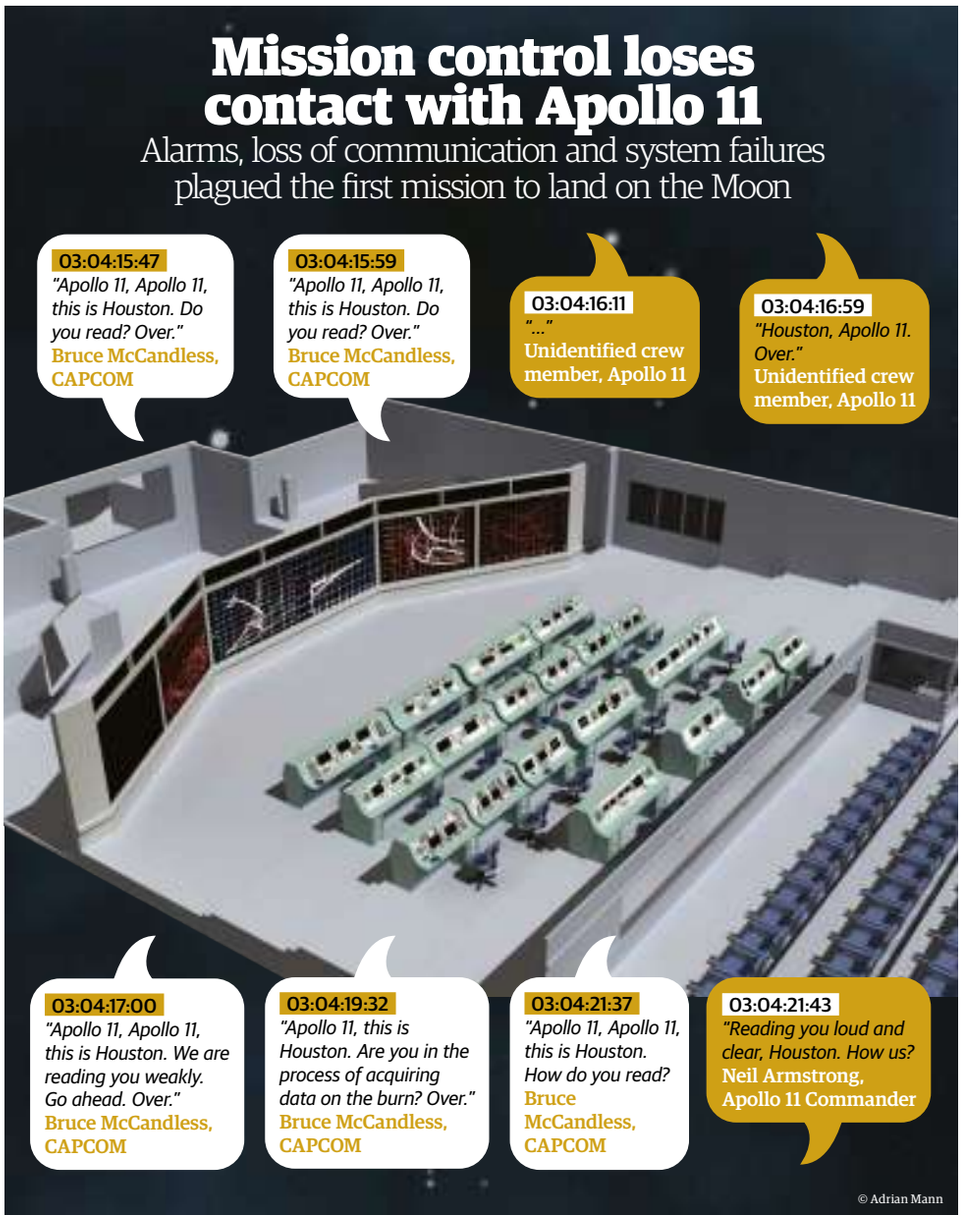




"The surface is fine and powdery. I can pick it up loosely with my toe. It does adhere in fine layers like powdered charcoal to the sole and sides of my boots. I only go in a small fraction of an inch, but I can see the footprints of my boots and the treads in the fine particles."
Neil Armstrong, Apollo 11 Commander



"Roger, Tranquility. We copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again. Thanks a lot."
Charlie Duke, CAPCOM





The Apollo 11 astronauts, left to right, Neil Armstrong, Michael Collins and Edwin 'Buzz' Aldrin inside the Mobile Quarantine Facility are greeted by President Nixon on 24 July 1969



Inside view of the Apollo 11 lunar module shows astronaut Buzz Aldrin during the lunar landing mission, an image taken by Neil Armstrong

to take the Eagle over the boulder field. But now fuel was running low and there was no turning back. Armstrong had to land the Eagle – somewhere, within minutes – or they would be out of fuel and crash.

"We'd never been this close in training," said Kranz. "We started a stopwatch running, with a controller calling off seconds of fuel remaining."

If things were tense in mission control, onboard the Eagle, Armstrong and Aldrin had everything under control. With only 13 seconds of fuel left Apollo 11 made its safe landing in the Sea of Tranquillity. History had been made. "Houston, Tranquility Base here," Armstrong radioed home. "The Eagle has landed."

In private, Aldrin took out a small cup, some wine and bread and said Holy Communion. The wine, under one-sixth Earth gravity, apparently curled up in the cup. After reading a section of the Gospel of St John, Aldrin said a few words, with Armstrong respectfully just looking on. NASA had been threatened with legal action by Madalyn

> "We started a stopwatch running, with a controller calling off seconds of fuel remaining" **Gene Kranz**

O'Hair, an atheist, after the crew of Apollo 8 had read from the book of Genesis, so Aldrin's heartfelt ceremony never made it to the airwaves. Aldrin, though, has always been content in the thought that the first food and drink consumed on the lunar surface were communion items.

The original plan had been for the crew to get some sleep, but with that much adrenaline pumping through their veins that was never going to happen. So at 2:39am on the morning of 21 July, Armstrong made his way through the hatch and down the ladder before stepping foot for the first time on the surface of the Moon and saying those immortal words, "That's one small step for [a] man, one giant leap for mankind."

Armstrong and Aldrin only had a few hours to not only collect precious rock samples, but also deploy a series of experiments on the lunar surface. Solar wind experiments, a laser retro-reflector that is still used to this day to measure the Earth-Moon distance, seismometers, and more were all deployed. Armstrong is cited as saying he felt like a five-year-old in a candy store, with not enough time to do all the things he wanted to.

Standing on the Moon must have been an incredible experience. Aldrin described the scene around him as one of "magnificent desolation", adding that, "You could look at the horizon and see very clearly because there was no atmosphere, there was no haze or anything."

As Armstrong walked around setting up instruments and picking up rocks, Aldrin hopped around on the surface, testing what the best way to move about in the low gravity was. Most of the pictures taken during the landing are of Aldrin on the surface; barely half a dozen show Armstrong, and none clearly. That's because Armstrong had the camera for most of the Moonwalk.

While on the surface, the crew also had terrific problems with the American flag. It had a telescoping boom arm to hold it out in lieu of any wind to hold it up. The two crew wrestled to get the boom arm to extend fully, but it would not, so the flag had a small kink in it. They also found that it was almost impossible to get the flag pole to go deep enough into the ground and, in the end, they only just managed to get it to stay upright. Both of the crew worried it would fall over live on TV, and probably as President Nixon was on the phone to them. But it remained upright during the broadcasts and telephone calls.

After collecting their rocks and clambering back into the lunar module, the crew took off their boots and backpacks, and began to throw anything not of vital importance back on to the lunar surface. This included urine bags, empty food packs, empty cameras and so on. But to the crew, they were just getting in the way and not needed.

There was time for one final crisis. The interior of the lunar module was cramped and, moving around in their bulky spacesuits, one of the astronauts had knocked out the switch for the circuit breaker that fired the ascent rocket that would take them home.

This was a real bottleneck moment for the mission. "If for some reason the ascent engine didn't work, there was no way to rescue the crew," said Kranz. Armstrong and Aldrin would be stranded on the Moon. The concern was so serious that President Nixon had a speech prepared, while mission control would close down communications with Armstrong and Aldrin after a clergyman had "condemned their souls to the deepest of the deep." Without that circuit breaker the crew were facing that lonely fate, but their training would not have allowed them to give up. "Rather than worry about things like that, we'd face them when the time came and we'd work as hard as we could to fix the problem until our oxygen ran out," said Aldrin.

In the end, the solution was remarkably simple. Jabbing the end of a pen into the slot where the broken switch had been, Aldrin was able to push the circuit breaker in. The ascent rocket fired and the two Moonwalkers were on their way home, via a rendezvous with Michael Collins in the command module. As the Eagle took off, the flag finally did blow over, and to this day it lays flattened, bleached out by solar radiation.

Over 50 years since that first successful landing on the Moon, stories still come out, not just from the thoughts of the crew, but also the almost 400,000 others who worked on the mission, from 'the guy sweeping the floor' back on Earth at Cape Canaveral, to the flight directors and flight controllers still, without whom the historic landing may never have happened. With our return to the Moon still some way off, these stories are all we have for now.

HOW TO...

Use a felt-tipped pen to escape from the Moon

After a circuit breaker switch broke off in all the too-ing and fro-ing in the cramped environment of the lunar module, Buzz Aldrin had to improvise in order to escape the Moon





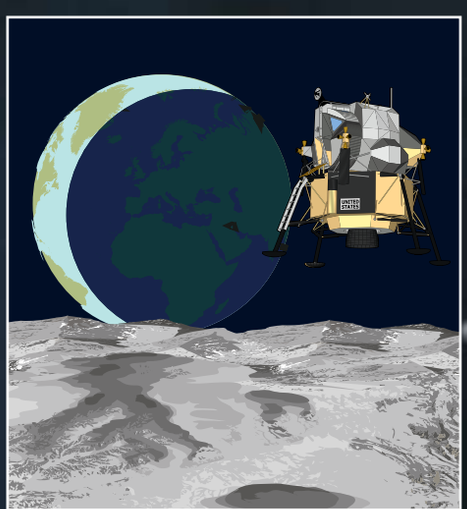
1 Astronauts locate broken circuit breaker switch

Neil Armstrong and Buzz Aldrin were gathering themselves into the landing module to start the return back to Earth when Aldrin noticed something lying on the floor – the circuit breaker switch had gotten bumped and had broken off.

2 Aldrin and Armstrong alert mission control

This switch was needed to activate the ascent engine to lift them off the Moon. Telling mission control, they tried unsuccessfully to catch some sleep but, by the following morning, NASA had no solution so Aldrin was forced to come up with his own fix for the problem.





3 Saved by a felt-tipped pen

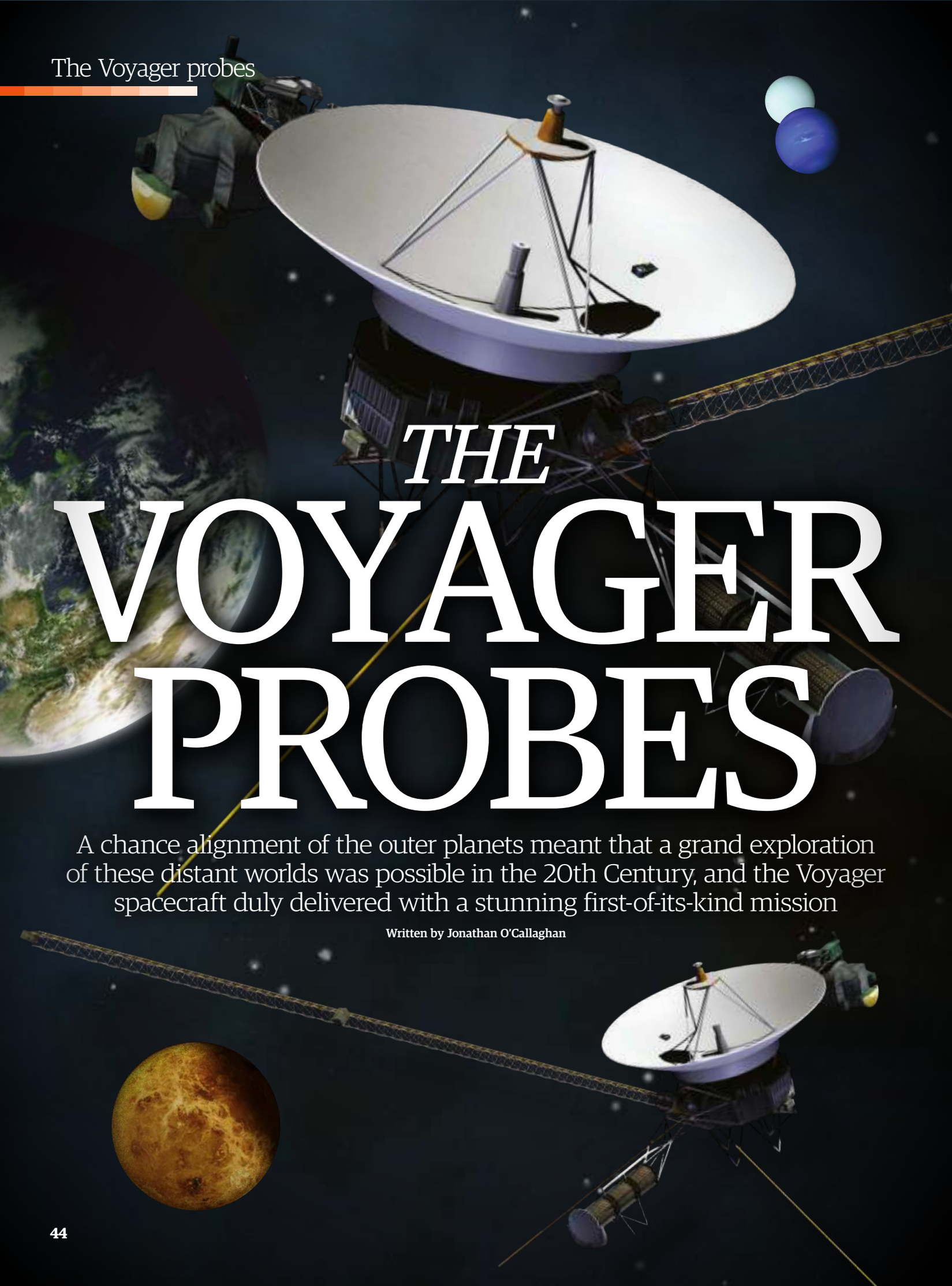
Since the circuit was electrical, sticking his finger or anything metal in wasn't possible. Instead, Aldrin found a felt-tipped pen in his shirt and inserted it into the opening where the circuit breaker switch should have been. He moved the countdown procedure up by a couple of hours.

4 Lift off!

The circuit breaker held, allowing both Aldrin and Armstrong to lift off from the surface of the Moon and intercept Michael Collins, who was in orbit around the Moon.

© Ed Crooks

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THE VOYAGER PROBES

A chance alignment of the outer planets meant that a grand exploration of these distant worlds was possible in the 20th Century, and the Voyager spacecraft duly delivered with a stunning first-of-its-kind mission

Written by Jonathan O'Callaghan

In the last seven decades, humans have explored much of the Solar System. We have landed probes on the surface of Venus, searched for life on Mars, examined the fascinating moons of Jupiter and Saturn and much more. But among the wide multitude of spacecraft that have made their mark on the Solar System, only two have ever managed to leave it entirely: NASA's Voyager 1 and Voyager 2 spacecraft. These two pioneering projects have been like none other, and today, their continuing missions as our only emissaries into the wider galaxy continues. But where did it all begin, and what did they do?

The story begins in the 1960s, when scientists first realised that a rare alignment of the planets would allow for a first-of-a-kind space mission. Called the 'Grand Tour', an alignment of the outer planets Jupiter, Saturn, Uranus, and Neptune in the late 1970s that occurred just once every 175 years meant that it was possible for a spacecraft to fly past all of them without major changes to its trajectory, meaning you could explore all four planets for the price of one launch. Upon this realisation, NASA scientists eagerly began designing a mission that could make the most of this.

Initially part of NASA's Mariner program that explored the planets Mercury, Venus and Mars, this program eventually progressed under its own name: Voyager. Initially, the idea was to send four spacecraft, which would have included flybys not just of the four outer planets, but of Pluto, too - which at the time was still technically a planet, but today is classed as a dwarf planet. A dauntingly large cost of $1 billion (£730 million), however, meant that the program was whittled down to two spacecraft, which became known as Voyager 1 and Voyager 2.

Both spacecraft were identical in design. With a mass of about 825 kilograms, they were each equipped with a large dish to communicate with Earth, a nuclear power system known as a radioisotope thermoelectric generator (RTG), and ten different science instruments to study the different worlds they would visit. These included advanced cameras to take stunning pictures of these worlds, infrared and ultraviolet instruments to study their atmospheres, and magnetometers to study their magnetic fields.

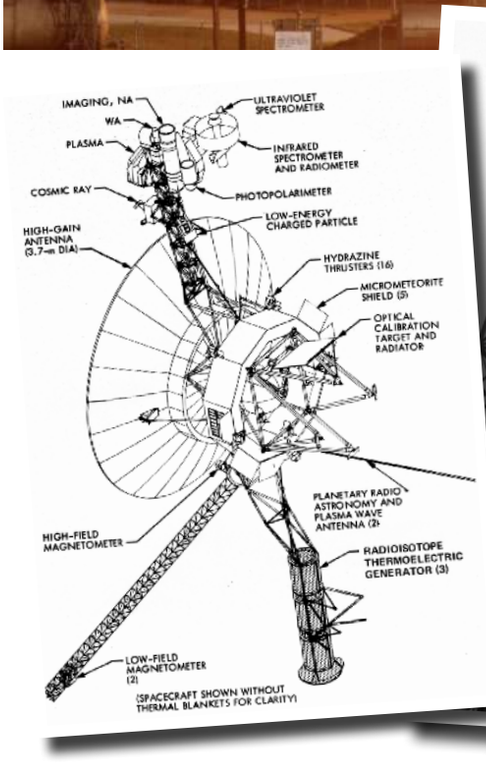
Despite the naming, Voyager 2 was the first of the two spacecraft to be launched. On 20 August 1977, it lifted off atop a Titan-Centaur rocket, beginning its long journey into deep space. Voyager 1 followed about two weeks later on 5 September on the same class of rocket, but this time launching on a much quicker trajectory - eventually reaching 38,000 miles per hour, versus 35,000 miles per hour for Voyager 2. It was designed to reach Jupiter and Saturn quickly, the former by 1979 and the latter by 1980, while Voyager 2 was on a slower trajectory that would see it reach Saturn in 1981. However, this slower path left open the option that if the spacecraft remained in working order, it could attempt a 'Grand Tour' and head for Uranus and Neptune.

Voyager 1 was designed with slightly curtailed objectives. Its goal was to fly past Jupiter and Saturn, the former of which had been visited by



The Voyager probes were sent into space on a pair of Titan-Centaur rockets

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Voyager 1's photo of Earth and the moon together in a single frame

©NASA

the Pioneer 10 spacecraft in 1973 and Pioneer 11 in 1974, and the latter visited by Pioneer 11 in 1979. Having been thrilled by these missions, scientists were ready for more data, and Voyager 1 delivered in a big way. The ambitious and exciting mission would also include a flyby of Saturn's tantalising moon Titan, which today we know to be the only place aside from Earth to have bodies of liquid on its surface. Many were thrilled at the prospect of exploring these worlds with this advanced spacecraft. What would it unearth on its incredible journey?

In 1978 Voyager 1 began its approach to Jupiter, taking regular images as it edged closer and closer. It finally entered the so-called Jovian system in February 1979, discovering a previously known thin ring surrounding the planet, which was only about 30 kilometres thick – and thus, unlike Saturn's magnificent ring, had been hard to spot. It ultimately made its closest approach to Jupiter in March, reaching just 280,000 kilometres above the planet, before then flying past many of its exciting moons including the volcanic world Io, the icy Europa, and the ginormous Ganymede. The spacecraft's studies of Io were particularly interesting, revealing that the moon was the most volcanically active world in the Solar System – even more so than Earth.

By November 1979 it had arrived at Saturn, where it would also make many fascinating discoveries. It found five new moons in the system and observed new properties of the fabulous Saturnian ring system. Of particular interest was the moon Titan, which Voyager 1 discovered had a thick atmosphere made of nitrogen like Earth, making the moon of huge interest to scientists. It wouldn't be until the joint ESA-NASA Cassini-Huygens mission launched later in the century that we would really understand how fascinating this moon was.

Following its encounter with the Saturnian system, Voyager 1's trajectory was purposefully bent by the gravitational pull, flinging it out of the system on an upwards path relative to the rest of the planets in the Solar System. This enabled it to begin a rapid path out of the Solar System, towards interstellar space, at a rate of about 523 million kilometres a year. While on its way, it turned back in 1990 to take a famous shot of Earth from a distance of six billion kilometres, called the 'Pale Blue Dot' – showing our planet as a tiny spec of light in the grandness of space, a fantastic portrait of our place in the universe. Ultimately, Voyager 1 would reach interstellar space in 2012, the first spacecraft in history ever to do so, when it was deemed to have left our Sun's influence known as the heliosphere.

Voyager 2's mission, meanwhile, followed behind. Its exploration of Jupiter, combined with data from Voyager 1, allowed scientists to map the surface of its moons Ganymede and Callisto, while it also provided vital information on a huge storm that had been raging on Jupiter for 400 years, known as the Great Red Spot. It also discovered four moons

Interstellar emissaries

While both Voyager spacecraft are expected to run out of power in the coming years, they will drift through the galaxy for eternity. And, in the unlikely scenario that an alien civilisation happens to discover them, engineers led by the famous late US astrophysicist Carl Sagan placed a few Easter eggs on board for them to learn about Earth.

Both spacecraft contain an identical 'Golden Record', packed with information about humanity and our planet. These records have etchings on them that reveal some of our knowledge, including the position of Earth relative to other stars (in case anyone wants to pay us a visit) and the structure of the hydrogen atom, showing our scientific potential. The two discs can also be played like vinyl records, with instructions given on how to do so. Contained within are sounds of our planet, including greetings in different languages, recordings of the natural world, and even images that can be displayed on a screen.

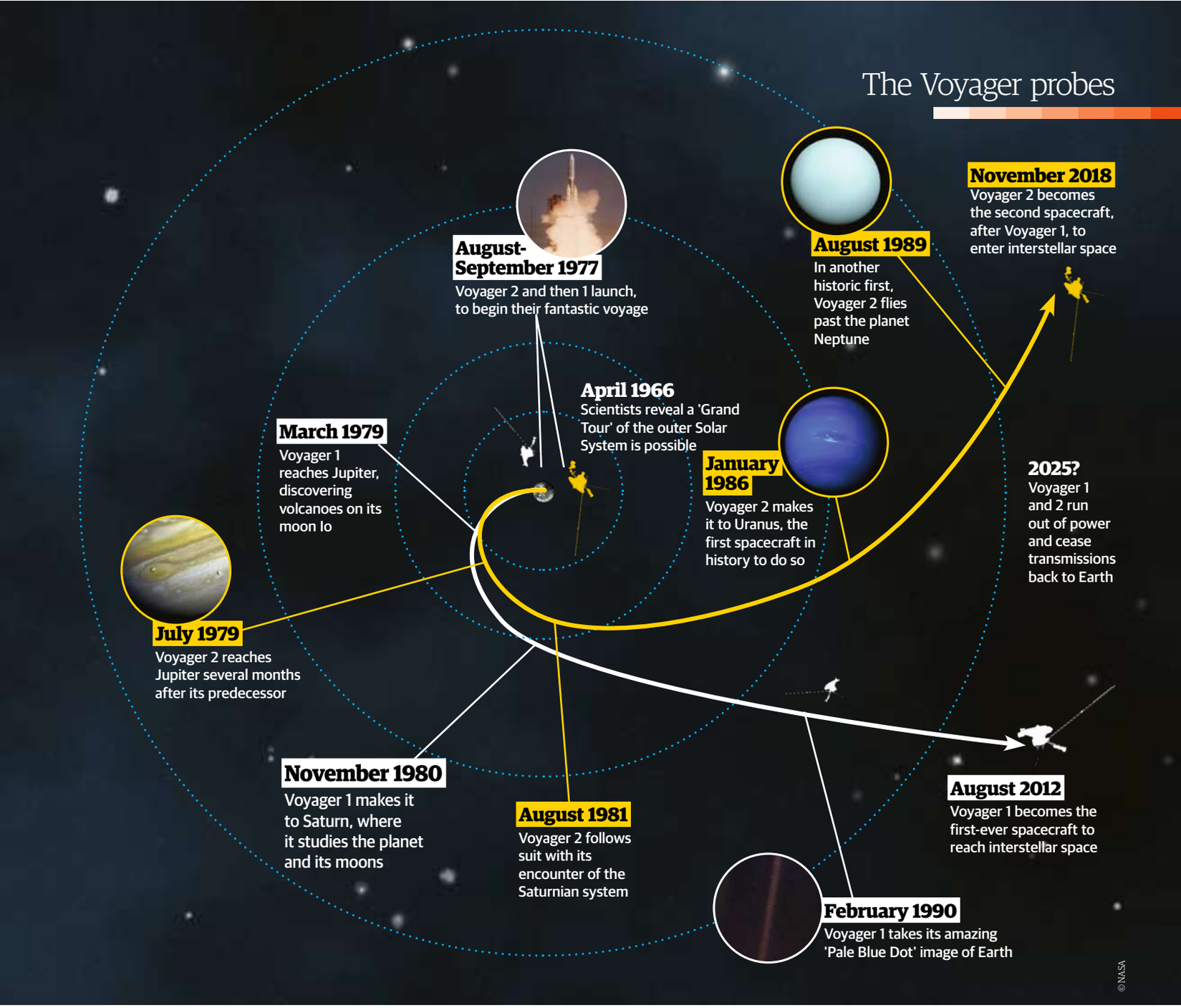
It's unlikely either spacecraft will ever be found in the vastness of the galaxy, especially given that their power will soon run out and they will no longer broadcast their locations. But regardless, it's comforting to know that a history of humanity will be stored forever on the two spacecraft.



©NASA

©NASA

An imprint of humanity is included on the Voyager probes in the form of the Golden Record



orbiting the gas giant, and provided additional data on its rings too. Later, it would reach Saturn, again providing fascinating images and measurements of the planet and its moons. But its most impressive feat was yet to come.

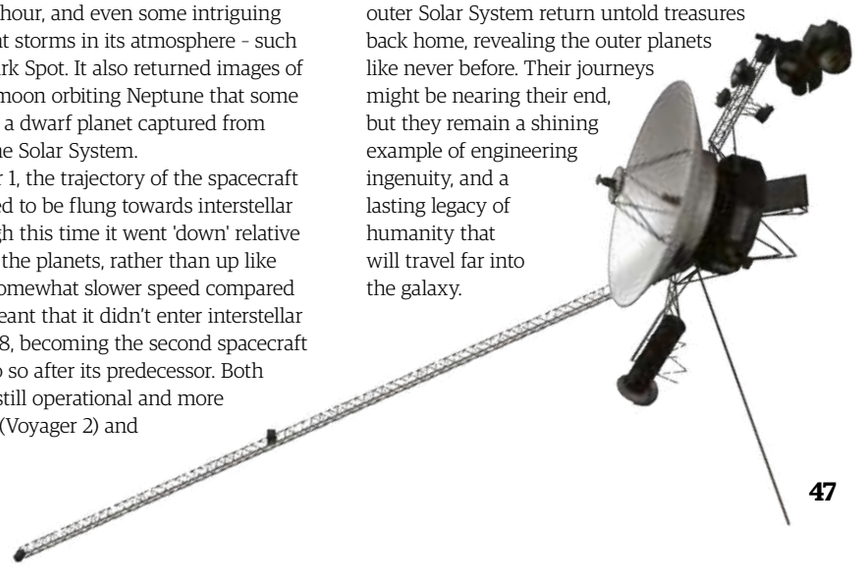
Given the spacecraft's good health, NASA decided to extend the mission and attempt to reach the ice giants Uranus and Neptune, our Solar System's two outermost planets. Neither planet had ever been visited by a spacecraft before, making Voyager 2's mission absolutely thrilling. After passing Saturn, it began the journey to Uranus, which would take four-and-a-half years. It began to approach the planet in November 1985, eventually making a close approach of just 81,500 kilometres above the planet on 24 January 1986.

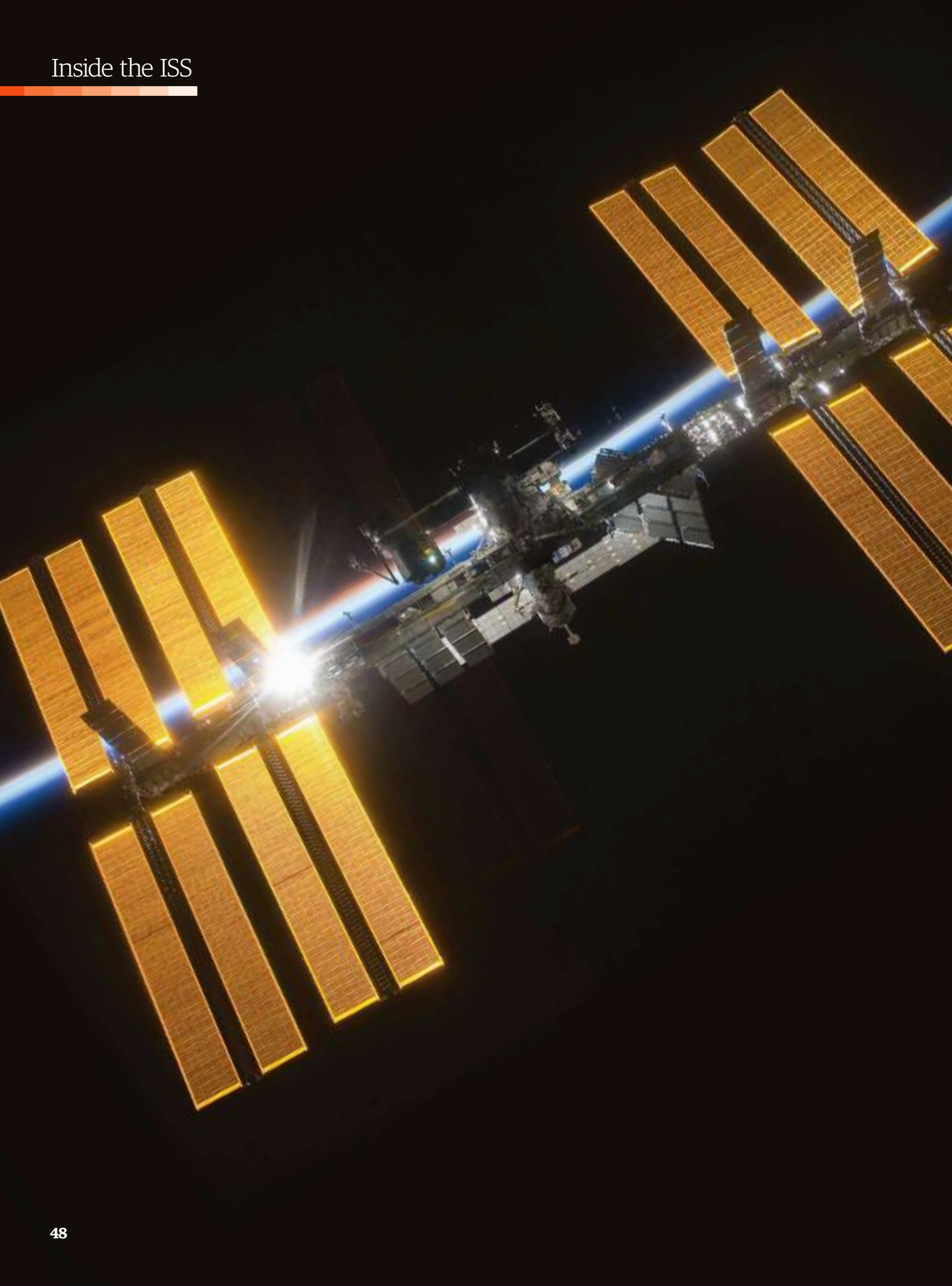
The event was beyond anything scientists could have hoped for. Not only did Voyager 2 return the first-ever close-up images and measurements of Uranus, revealing rapid winds in its atmosphere and an ocean of boiling water below its clouds, but it also found ten new moons in the system and two new rings. It provided stunning images of these satellites, sending back fascinating visages of these alien worlds that had never been seen by human eyes before.

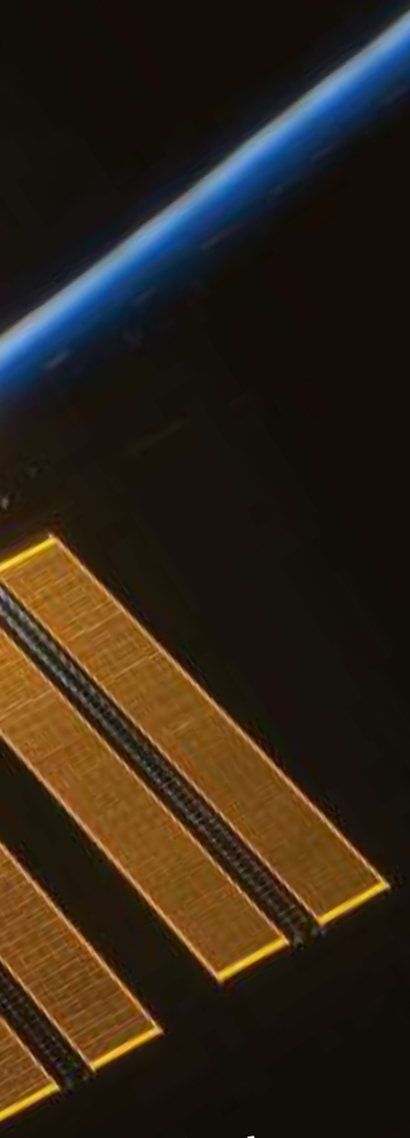
After that, it was on to Neptune, which the spacecraft reached on 25 August 1989. Again, this planet had never been seen up close before by human eyes. Voyager 2 not only discovered new moons and rings again, six and four respectively, but it also discovered the planet had winds of 1,100 kilometres per hour, and even some intriguing features of giant storms in its atmosphere – such as the Great Dark Spot. It also returned images of Triton, a large moon orbiting Neptune that some now think was a dwarf planet captured from elsewhere in the Solar System.

Like Voyager 1, the trajectory of the spacecraft was then altered to be flung towards interstellar space – although this time it went 'down' relative to the orbits of the planets, rather than up like Voyager 1. Its somewhat slower speed compared to its sibling meant that it didn't enter interstellar space until 2018, becoming the second spacecraft in history to do so after its predecessor. Both spacecraft are still operational and more than 18 billion (Voyager 2) and 22 billion (Voyager 1) kilometres from Earth, but their diminishing power has meant that only some of their instruments are still working. However, they are still sending information back to Earth, and are expecting to continue doing so until 2025.

There's little doubt that Voyager 1 and 2 remain two of the most incredible spacecraft devised and launched in history. Their incredible voyage of the outer Solar System return untold treasures back home, revealing the outer planets like never before. Their journeys might be nearing their end, but they remain a shining example of engineering ingenuity, and a lasting legacy of humanity that will travel far into the galaxy.







Inside the ISS

As the most expensive and ambitious structure ever assembled, the International Space Station has been an unequivocal success in its continuing mission to impart a wealth of knowledge upon all humankind

Written by Jonathan O'Callaghan

Twenty-two years ago on 20 November 1998, a Russian Proton rocket lifted off from the Baikonur Cosmodrome in Kazakhstan. Its payload was a single module called Zarya (Sunrise), funded by the US and built by Russia, that would serve as the first component of a global venture the likes of which had never been seen before.

Just over two weeks later, on 6 December 1998, Space Shuttle Endeavour – flying on the STS-88 mission – took the US-built Unity module into space and berthed it with Zarya. With the connection of these two inaugural modules, construction on the International Space Station (ISS) had begun.

The ISS is perhaps the greatest example of what can be achieved through international co-operation. With a cost estimated at around $100 billion (£63 billion) – the most expensive man-made structure ever assembled – the logistics and planning of building and operating a space station of this size have been stupendous. Today, many members of the public take the ISS for granted, with astronauts and cargo regularly making their way to and from the station 420 kilometres (260 miles) above the Earth seemingly with ease, but the construction and operation of this marvel have been anything but easy.

"We've learned a lot since that first module," says John Shannon, the ISS programme manager for Boeing. He was the launch flight controller for NASA when Endeavour undertook that fateful mission in 1998. Having worked at NASA for 25 years before joining Boeing in the 2010s, Shannon oversaw the development and growth of the ISS into the marvel we know it to be today.

"I think the really tough part to me of learning how to build this enormous structure in space was that it had to be a viable spacecraft the whole time," says Shannon. "It wasn't just like a ship you can build in dry dock and launch when it's all finished up; we had to really think through how all the systems would work as we were building it out in the most hazardous environment that people can operate in."

Building the ISS has not only been a technical challenge, but a political and logistical one as well. The station was borne out of the cancelled American Space Station Freedom and Russian Mir-2 programmes, with those two projects merging, along with commitments from other international partners including Japan and Europe, into the space station in operation today.

Space Station Freedom was first proposed in the early Eighties, but cost overruns and budget cuts saw the programme continually delayed. In June 1993, a crucial vote in the House of Representatives saw an attempt to scrap the programme fail by a one-vote margin (215-216). Had the programme been abandoned, it is likely the ISS as we know it would not have been built, as many of the components from Freedom have been incorporated into its design.

Another pivotal moment in the development of the ISS was the decision by the Clinton administration in September 1993 to partner with

> "Now we're really into the utilisation and we're starting to see this eye-watering breadth of activity"
>
> **John Shannon**

Inside the ISS

Russia in the station's construction. NASA was finding the prospect of building a station of the scope and size of the International Space Station to be a daunting prospect, both financially and technically. Russia's involvement would prove vital; they could supply several of the modules needed for a fully operating station, as well as the Soyuz and Progress spacecraft needed to take crew and cargo into orbit.

"That was a very difficult and intense time, to see how the two primary countries [the US and Russia] could work together with the other [international] partners to build the station," explains Shannon. "But once we launched the first elements in 1998, we had a really good idea of what the overall plan was going to be."

The plan for the ISS was ambitious, to say the least. While it was preceded by a number of space stations, namely America's Skylab and Russia's Mir and Salyut stations, none of those could compare in size and complexity to the ISS. Here was a station that would be as big as an American football field upon its completion and weigh more than 320 cars on Earth, while also providing a habitable environment in which astronauts could live.

Soyuz spacecraft could take crews to the ISS, but it was the Space Shuttle that would be the key to building it; the robotic arm on board the Space Shuttle was needed to berth various modules together. However, the Space Shuttle Columbia disaster on 1 February 2003 led to the station's construction being put on hold while the Space Shuttle programme was grounded for two and a half years due to safety concerns.

Aside from that period, construction of the ISS has continued unabated to the point that many regard the station to be complete and fully operational, although some further modules are planned. The ISS has now been continuously manned for a record of over 4,600 days since 2 November 2000 when Expedition 1 began, the first long-duration crew to reside on the ISS, surpassing the previous record of almost ten years (3,634 days) held by Mir.

"The building was the first big thing," explains Shannon, "and now we're really into the utilisation and we're starting to see this eye-watering breadth of activity." Since its inception, the International Space Station has had numerous goals, but it has focused on three main areas. The first is research that could improve life on Earth. Hundreds of experiments are running on the ISS at any one time, and many of these have direct connotations for counterparts on Earth. This includes medical research, physical sciences, curing diseases and developing new materials. Through this goal alone the ISS has more than proved its worth.

The ISS has also been hugely important in terms of the future of space exploration. "With the Shuttle we were limited to two weeks [in space]," says Shannon. "[On the ISS] we've seen physiological changes in bones and eyes, pressure on your spinal cord, and a lot of different things that we never would have known if we were just doing two-week flights on the Shuttle. If we would have set off to go to an asteroid or Mars for months-long missions they could have debilitated the crew such that

1. This photo from STS-88 in December 1998 shows the ISS in its infancy with just the Zarya and Unity modules assembled.

2. The arrival of the three-man crew of Expedition 1 on 2 November 2000 began a period of uninterrupted human occupation of the ISS that continues to this day.

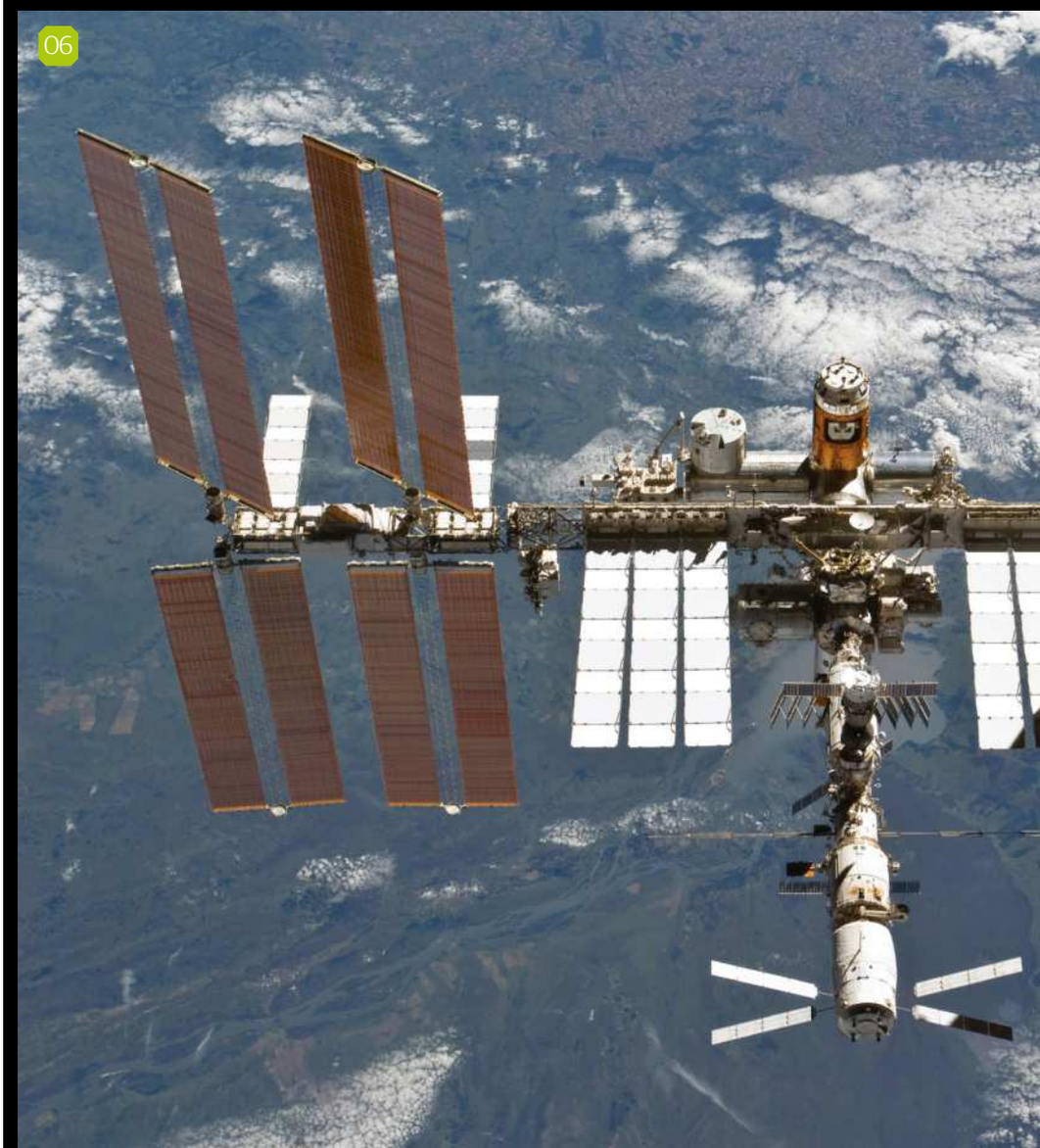
3. Expedition 20, which docked on 29 May 2009, marked the first time a six-person crew had inhabited the space station.

4. Canadarm2, seen here with astronaut Stephen Robinson in August 2005, has played a key role in the assembly and maintenance of the ISS since it was attached in April 2001.

5. The Cupola module opened its shutters on 17 February 2010, affording ISS crewmembers gorgeous vistas of Earth and space.

6. The ISS, seen here in March 2011, is now effectively complete, although there are plans to install new modules and components in the future.









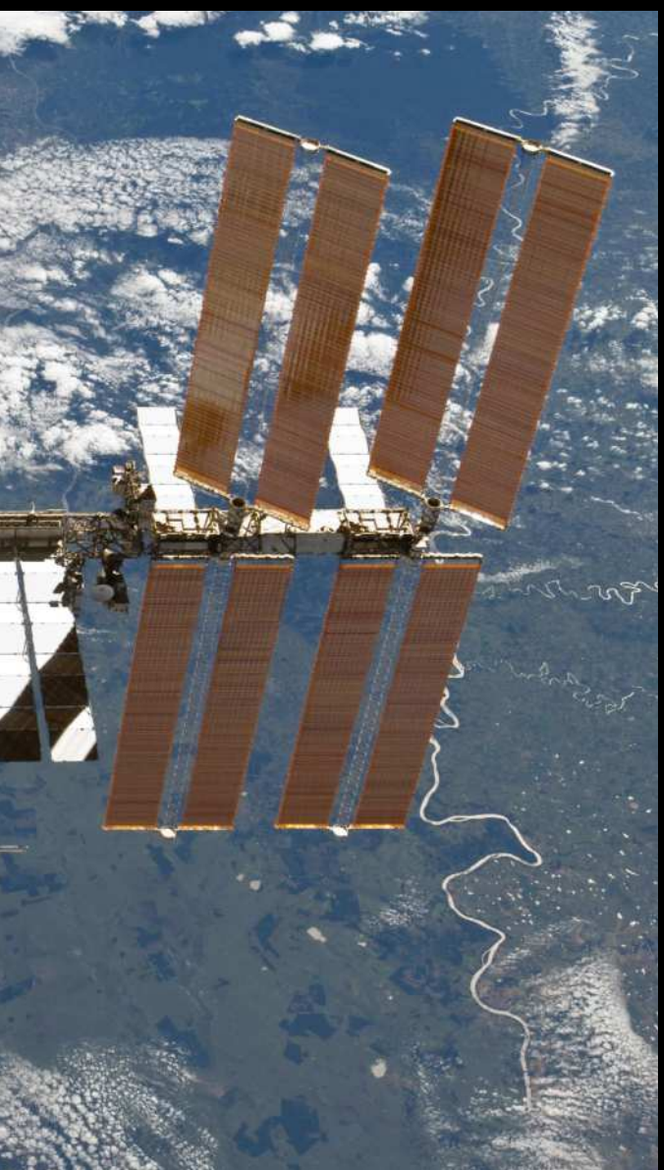
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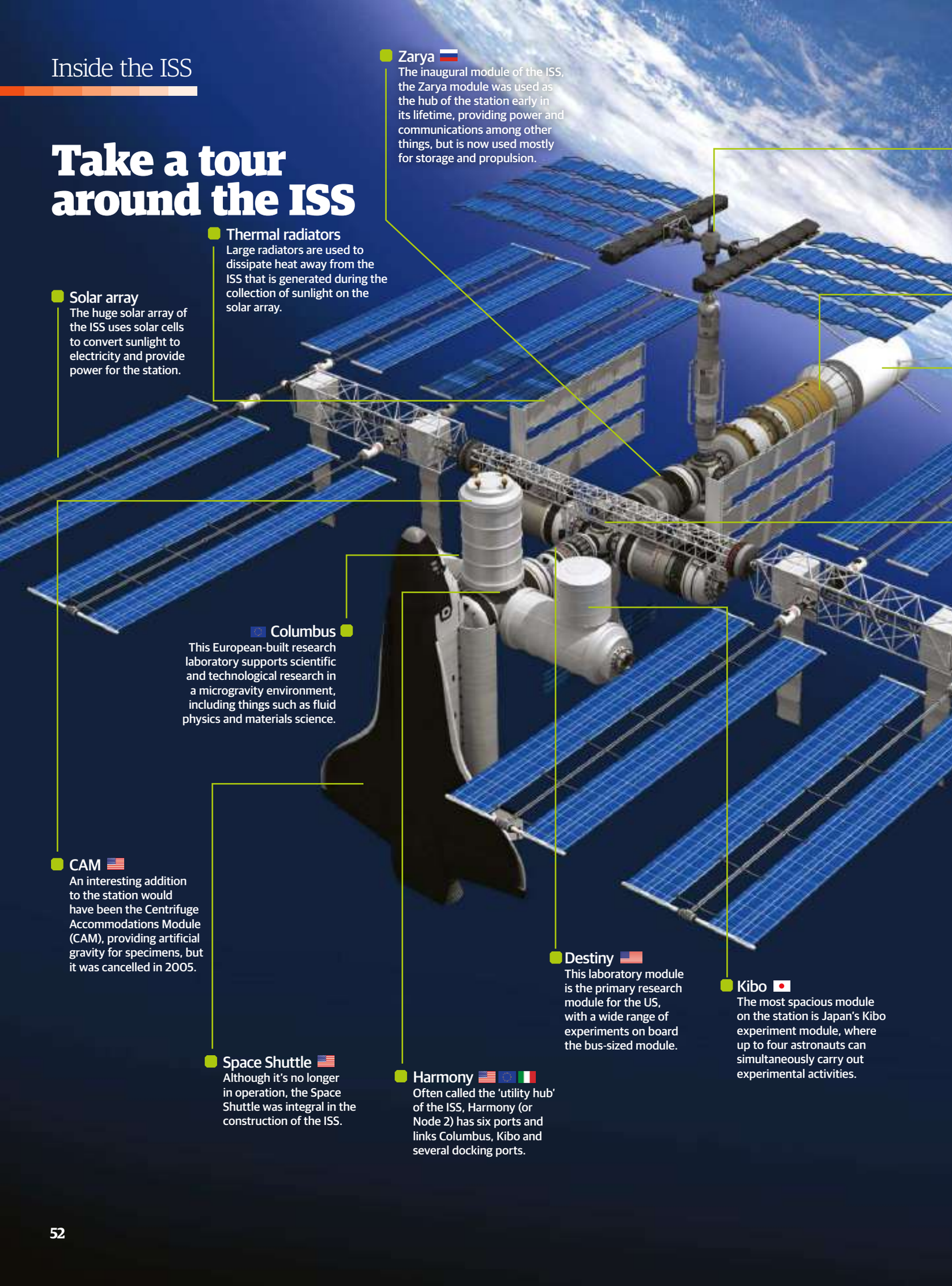
04





05

Take a tour around the ISS



Zarya
The inaugural module of the ISS, the Zarya module was used as the hub of the station early in its lifetime, providing power and communications among other things, but is now used mostly for storage and propulsion.

Thermal radiators
Large radiators are used to dissipate heat away from the ISS that is generated during the collection of sunlight on the solar array.

Solar array
The huge solar array of the ISS uses solar cells to convert sunlight to electricity and provide power for the station.

Columbus
This European-built research laboratory supports scientific and technological research in a microgravity environment, including things such as fluid physics and materials science.

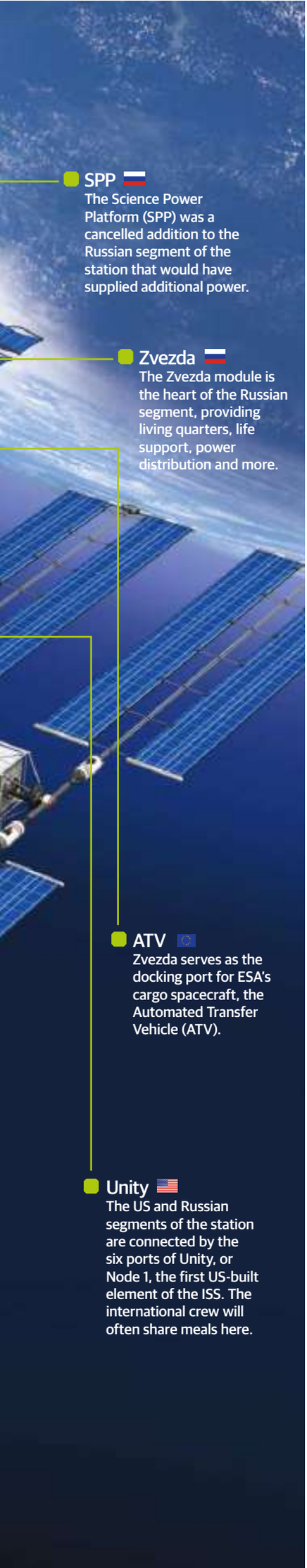
CAM
An interesting addition to the station would have been the Centrifuge Accommodations Module (CAM), providing artificial gravity for specimens, but it was cancelled in 2005.

Space Shuttle
Although it's no longer in operation, the Space Shuttle was integral in the construction of the ISS.

Harmony
Often called the 'utility hub' of the ISS, Harmony (or Node 2) has six ports and links Columbus, Kibo and several docking ports.

Destiny
This laboratory module is the primary research module for the US, with a wide range of experiments on board the bus-sized module.

Kibo
The most spacious module on the station is Japan's Kibo experiment module, where up to four astronauts can simultaneously carry out experimental activities.



SPP
The Science Power Platform (SPP) was a cancelled addition to the Russian segment of the station that would have supplied additional power.

Zvezda
The Zvezda module is the heart of the Russian segment, providing living quarters, life support, power distribution and more.

ATV
Zvezda serves as the docking port for ESA's cargo spacecraft, the Automated Transfer Vehicle (ATV).

Unity
The US and Russian segments of the station are connected by the six ports of Unity, or Node 1, the first US-built element of the ISS. The international crew will often share meals here.

"It's the greatest technological achievement that humans have gotten to at this point"

Tom Marshburn



they couldn't have accomplished their mission, or they could have come to great harm, so the ISS is this wonderful safe test bed where you can experiment on crews so that when we do go beyond low Earth orbit we can do so much more safely."

The third key use of the ISS is to serve as a destination for a new generation of spacecraft designed by both national and private space agencies. Throughout its lifetime it has welcomed the Space Shuttle, Russia's Soyuz and Progress, the Japanese HTV (H-II Transfer Vehicle), the European ATV (Automated Transfer Vehicle) and, most recently, SpaceX's Dragon capsule. One of the newest additions was the Cygnus spacecraft, built by Orbital Sciences, which competed with SpaceX for commercial cargo contracts from NASA. And the visitors don't stop there; in the future Boeing aims to dock its manned CST-100 capsule to the station, while Sierra Nevada Corporation wants its Dream Chaser spaceplane to visit the ISS.

Life on the station "is spectacular, in a word," according to NASA astronaut Tom Marshburn, who was part of the Expedition 34/35 crew that included Canadian astronaut Chris Hadfield and stayed aboard the ISS from 21 December 2012 to 13 May 2013. For those astronauts that live aboard the ISS, the constantly visiting spacecraft are just one aspect of the exciting jobs they enjoy. "I don't think it's overstating it to say it's the greatest technological achievement that humans have gotten to at this point," Marshburn explains.

For Marshburn life on the ISS was both "exhausting and exciting", with their intense mission schedules countered with their ability to see gorgeous views of the Earth from a vantage point enjoyed only by a few hundred people. "I was constantly astounded by what human beings from around the world had accomplished," said Marshburn. "It really hits you when you get there and when you think of almost two acres of technology going 28,000 kilometres (17,500 miles) per hour and we're living in the middle of it. It's just a dream come true in a lot of ways."

On board the ISS, the astronauts have a lot of work to do. Although the station experiences a sunrise and sunset every 90 minutes as it orbits the Earth, the astronauts still structure their days like they would on Earth. They operate on GMT, waking in the morning before completing tasks throughout the day. These can range from station maintenance and experiments to, on rare occasions, extravehicular activities (EVAs, or spacewalks) outside the station. They are afforded some 'downtime' to relax, which many astronauts like to make use of by heading to the Cupola module and staring at the Earth or taking pictures, before heading to bed at night in their telephone booth-sized private quarters. Every day they must also do two and a half hours of exercise to ensure their body survives the adverse effects of living in a microgravity environment, such as the decreased bone mass that can occur.

The International Space Station itself is big, with a typical size estimate comparing it to an elongated five-bedroom house, so when astronauts first arrive at the station it can feel like a bit of a maze. "You're like a deer in the headlights, definitely on your first day," explains Marshburn. "After the third or fourth month, that's when you realise you're a part of the station, that it's almost another crewmember. You know its intricacies, its sounds, and the certain feel it has about it. It develops a personality."

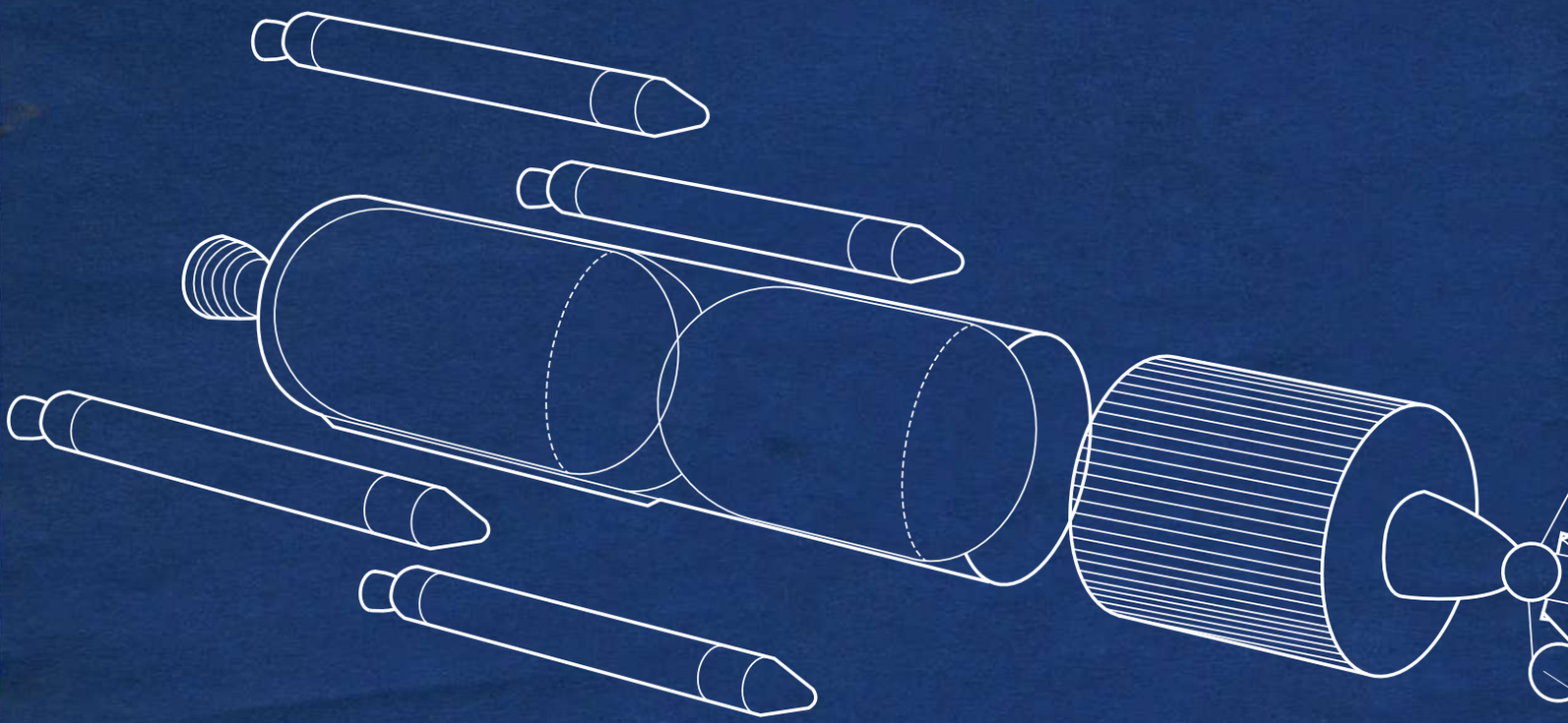
Despite the incredible complexity of the station, Marshburn says that the most difficult things to do in space are things we take for granted here on Earth. "The easy things down here are the most difficult things up there," he says. For example, "you'll lose any little thing you put down that you haven't already figured out a way to restrain. One thing you figure out in space is that if you're only going to put something down for just a moment you can float it, just let go of it, and come back ten seconds later and it'll still be there."

These simple quirks of spaceflight as well as grand experiments like the Alpha Magnetic Spectrometer, which is hunting for signs of dark matter, are a testament to just how much the ISS has benefitted mankind, and there's still much to learn. While the operating lifetime of the ISS is currently under discussion, with the preference being to keep the station running until 2030, those involved with the space station are anxious to keep it going as long as possible. Ultimately there will come a time when we no longer have the means or will to maintain the station, but until then there is plenty more to do.

"Fifteen years from now we'll be thinking about [de-orbiting the ISS]," says Shannon. By then, our knowledge of space exploration will be such that we can safely and effectively expand our sphere of influence in space, and we will have performed groundbreaking science along the way in experiments that couldn't be replicated on Earth.

When the time comes to bring the curtain down on mankind's greatest endeavour yet - which is speculated to be 2030 at the earliest - we will have kept a continuous presence in space for almost three decades. By that time, we will truly be ready to explore brand-new frontiers. "We will have learned what we need to learn about people's reaction to space so that we can go farther and deeper into space," concludes Shannon. "I think that's going to be the legacy of the International Space Station." ●

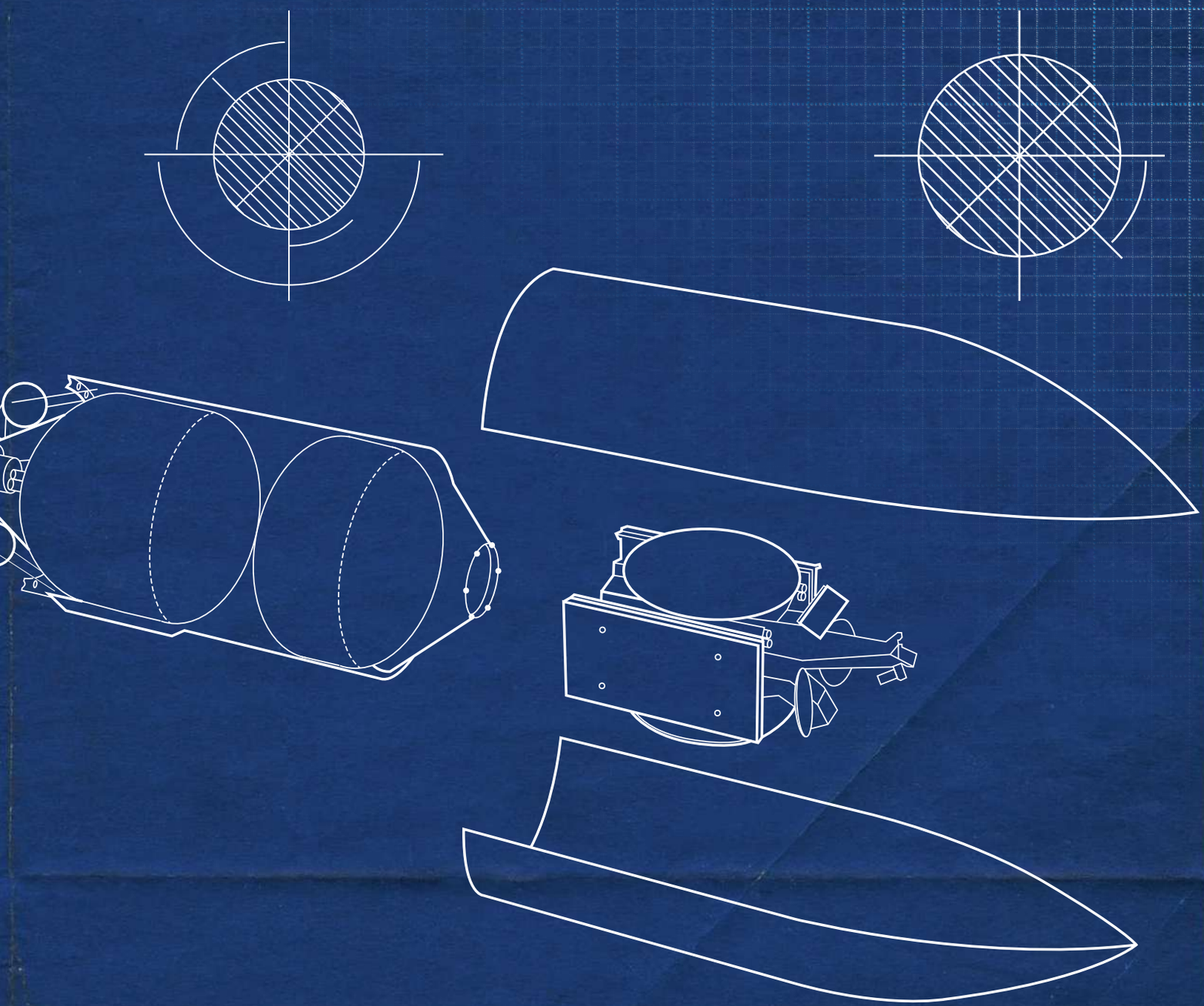
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Bluffer's guide to ROCKET SCIENCE

Rockets of all kinds are still our only way of reaching space – but just how do they work?

Written by Giles Sparrow



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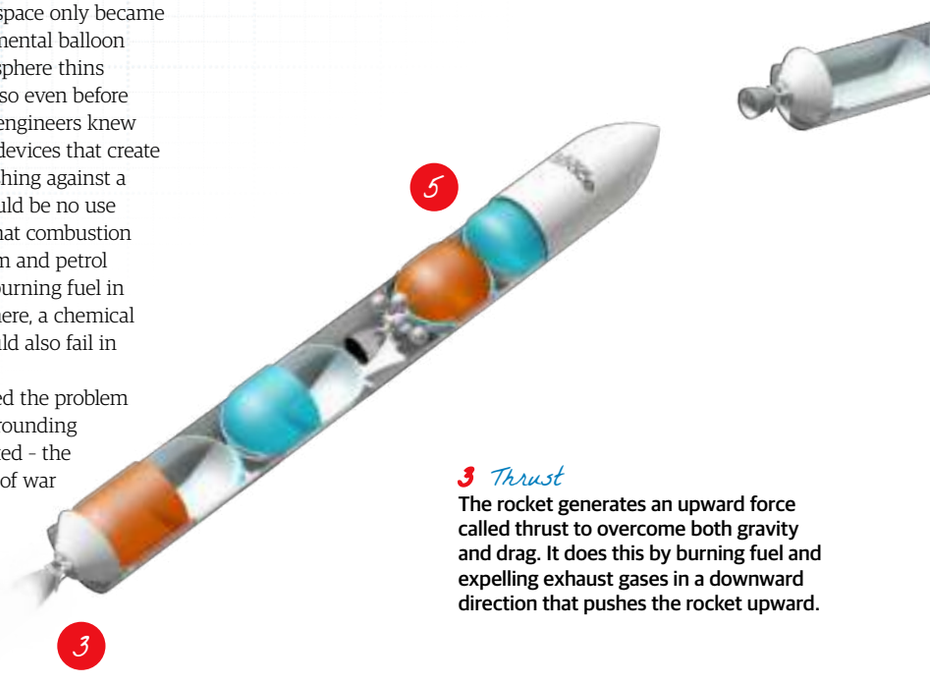
1 How rockets lift off

Rockets burn through most of their fuel in the first few minutes of their flight as they battle against Earth's gravity

Writers and inventors have dreamt of exploring the universe beyond Earth for centuries, but the real challenges of travelling into space only became clear in the 19th century. Experimental balloon flights showed that Earth's atmosphere thins out rapidly at high altitudes, and so even before powered flight became a reality, engineers knew that wings, propellers and other devices that create a forward or upward force by pushing against a surrounding medium like air would be no use in space. Another problem was that combustion engines – machines such as steam and petrol engines that generate power by burning fuel in the oxygen from Earth's atmosphere, a chemical reaction called combustion – would also fail in airless space.

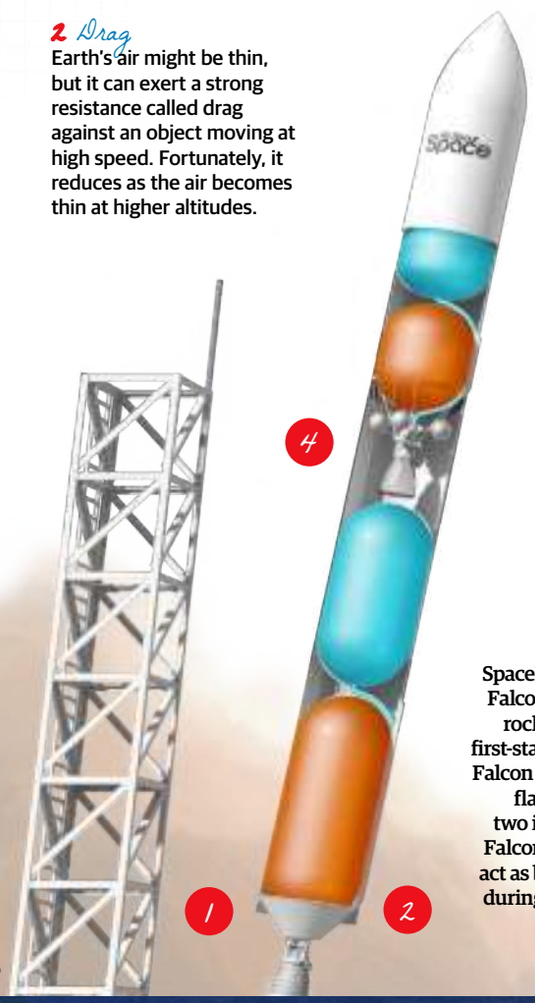
Fortunately, a device that solved the problem of generating force without a surrounding medium had already been invented – the rocket. Initially used as weapons of war

1 Gravity
The force of gravity pulls everything towards the centre of the Earth, exerting a downward force of 9.8 newtons per kilogram on every part of the rocket.



3 Thrust
The rocket generates an upward force called thrust to overcome both gravity and drag. It does this by burning fuel and expelling exhaust gases in a downward direction that pushes the rocket upward.

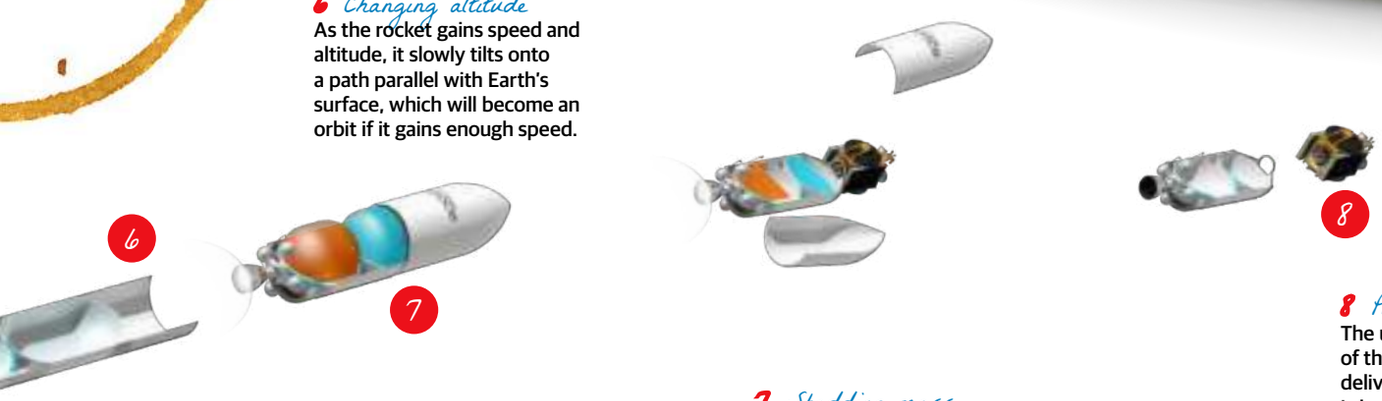
2 Drag
Earth's air might be thin, but it can exert a strong resistance called drag against an object moving at high speed. Fortunately, it reduces as the air becomes thin at higher altitudes.





Right: SpaceX's huge Falcon Heavy rocket has a first-stage 'core' Falcon 9 rocket flanked by two identical Falcon 9s that act as boosters during launch

© NASA; SpaceX; Adrian Mann



6 *Changing altitude*
As the rocket gains speed and altitude, it slowly tilts onto a path parallel with Earth's surface, which will become an orbit if it gains enough speed.

4 *Slow start*
At launch, a rocket's weight is at its greatest. Even with the rockets producing maximum thrust they produce barely enough power to lift the rocket off the ground.

7 *Shedding mass*
As the rocket continues to burn fuel, its weight reduces, so although the thrust force from its engines remains constant, it has a greater accelerating effect.

8 *Payload*
The uppermost stage of the launch vehicle, delivered into orbit, is known as the payload. This may consist of a satellite or spacecraft, often with a separate rocket stage for further manoeuvres.

5 *Rocket stages*
Most rockets are designed with two or more stacked units called stages. The lowermost stage fires its engines until they are exhausted, then separates and falls away to reduce the overall mass being carried further towards space.



Left: The Space Shuttle's unique design channelled propellant from an external tank to the Shuttle's main engines during launch, while two large solid rocket boosters assisted



"Rockets generate a force in one direction, called thrust, by the principle of action and reaction"

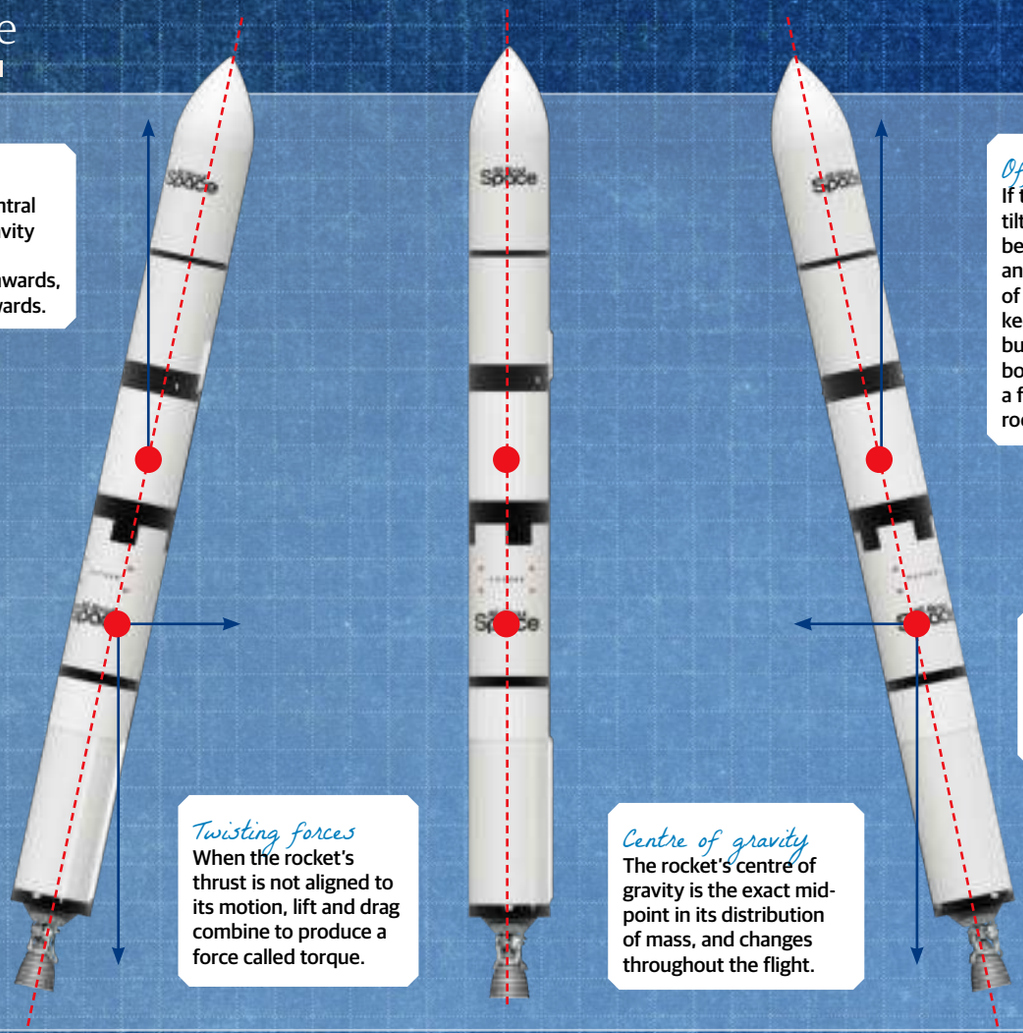
or in fireworks, rockets generate a force in one direction, called thrust, by the principle of action and reaction – exhaust fumes released by explosive chemicals are pushed out of the back of the rocket at high speed, and as a result the rocket is pushed in the other direction, regardless of any surrounding medium. The key to using rockets in space is simply to carry another chemical called an 'oxidant' that can perform the same role as oxygen in the Earth's air and allows the fuel to combust.

The first person to seriously study the rocket's potential for space travel, a Russian schoolteacher and amateur scientist called Konstantin Tsiolkovsky, first published his conclusions in 1903. He correctly identified the moment of launch as one of the biggest challenges – the moment where the rocket has to carry all the fuel and oxidant it needs to reach space – as its weight is at a maximum and a huge amount of thrust is needed simply to get it moving at all. As the rocket gets underway it sheds mass through its exhaust, so its weight is reduced and the same amount of thrust will have a greater effect in terms of accelerating the rest of the rocket. Tsiolkovsky came up with various rocket designs and concluded that the most efficient setup was a vertically launched vehicle with several 'stages' – each a self-contained rocket that could carry the stages above it for a certain distance before exhausting its fuel, detaching and falling away. This principle, still widely used today, reduces the amount of 'dead weight' that needs to be carried all the way into space.

Tsiolkovsky devised a complex equation that revealed the necessary thrust force needed for any given rocket manoeuvre, and the 'specific impulse' – how much thrust is generated per unit of fuel – needed for a rocket to reach space. He realised that the explosive rocket propellants of his time were far too inefficient to power a space rocket, and argued that liquid fuels and oxidants, such as liquid hydrogen and liquid oxygen, would ultimately be needed to reach orbit and beyond. Although he did not live to see his work recognised, Tsiolkovsky's principles still underpin all of modern rocketry.



The Delta II rocket's first-stage core was assisted by nine separate solid-rocket boosters during launch



Vertical ascent
Forces act all along its central axis, with the rocket's gravity and any drag due to air resistance pulling it downwards, and thrust pushing it upwards.

Restoring force
If the centre of pressure is below the centre of gravity, the torque force will tend to twist the rocket back to a stable path.

Fins or gimbals
Today most use gimballed rocket motors to adjust their direction instead of fins.

Twisting forces
When the rocket's thrust is not aligned to its motion, lift and drag combine to produce a force called torque.

Centre of gravity
The rocket's centre of gravity is the exact mid-point in its distribution of mass, and changes throughout the flight.

Off-axis flight
If the rocket's body is tilted, its thrust may be displaced by a small angle from the direction of its motion. Fins help keep the rocket stable, but they and the rocket's body both generate lift, a force that pushes the rocket to one side.

Centre of pressure
The centre of pressure is the point where the aerodynamic forces of drag and lift act.

2 Taking flight

Rockets must delicately balance and control powerful forces in order to make it through Earth's atmosphere into space



A rocket generates thrust using a controlled explosion as fuel and oxidant undergo a violent chemical reaction. Expanding gases from the explosion are pushed out of the back of the rocket through a nozzle – a specially shaped exhaust that channels the hot, high-pressure gas created by combustion into a stream that escapes from the back of the nozzle at hypersonic speeds, more than five-times the speed of sound.

Isaac Newton's third law of motion states that every action has an equal and opposite reaction, so the 'action' force that drives the exhaust out of the rocket nozzle must be balanced by an equal and opposite force pushing the rocket forwards. Specifically, this force acts on the upper wall of the 'combustion chamber', but since the rocket motor is integral to each rocket stage, we can think of it acting on the rocket as a whole.

Although the forces acting in both directions are equal, their visible effects are different because of another of Newton's laws which explains how objects with greater mass need more force to accelerate them by a given amount. So while the 'action' force rapidly accelerates a small mass of exhaust gas to hypersonic speeds each second, the equal 'reaction' force produces a far smaller acceleration in the opposite direction on the far greater mass of the rocket.

As the rocket gains speed, keeping the direction of motion closely aligned with the direction of thrust is critical – gradual adjustments are needed to steer the rocket towards an orbital trajectory, but a severe misalignment can send the rocket whirling out of control. Most rockets, including the Falcon and Titan series and the Saturn V Moon rocket, steer using 'gimballed' engines, mounted so that the entire rocket motor can pivot and vary the direction of its thrust from moment to moment. Other steering options include using external vanes to deflect the exhaust gases as they escape the rocket engine – most effective with solid-fuelled rockets that lack a complex motor – and auxiliary engines – small 'thruster' rockets mounted on the sides of the rocket stage.

> "Keeping the direction of motion closely aligned with the direction of thrust is critical"

© NASA; Adrian Mann; Beltez



1 Boosters
Solid rockets make ideal boosters for use during liftoff. Strapped around a central liquid-fuelled 'first stage', they fall away when exhausted.

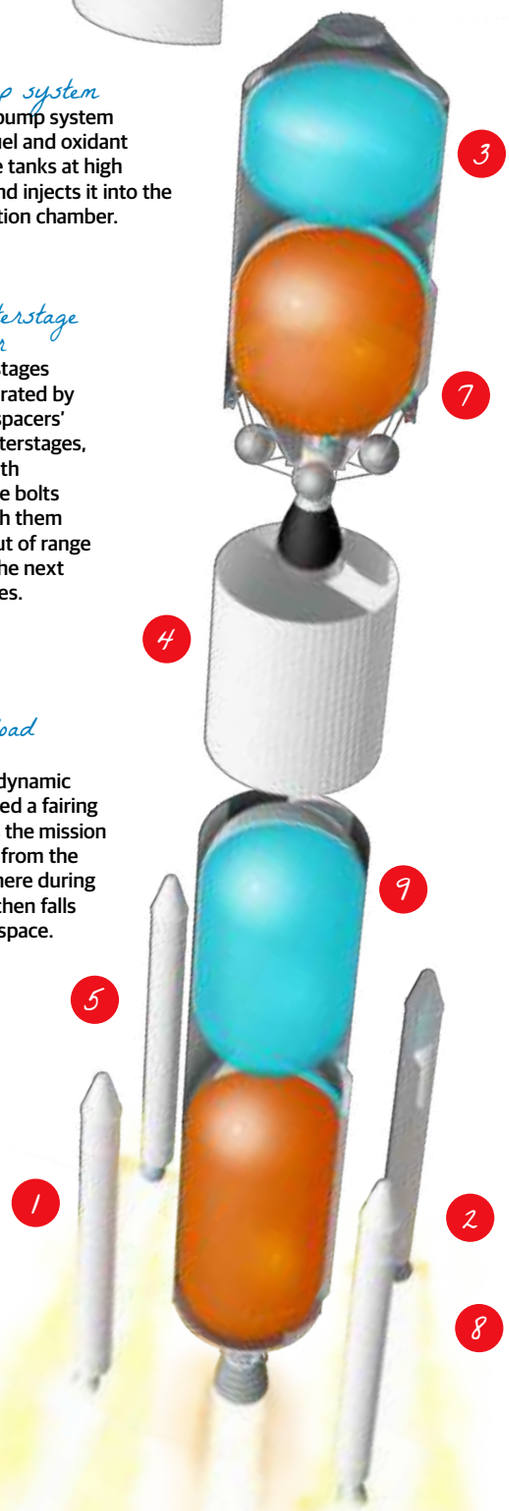
3 How a rocket's motors work

Rocket engines are complex machines that must endure ferocious heat and pressure

Modern rocket motors have come a long way from fireworks. Relatively simple solid rockets, most often used as boosters to provide extra thrust at launch, still rely on the same basic principle of igniting a tube containing a combustible mix of fuel and oxidant. Once ignited, a solid rocket will continue to burn until its fuel is exhausted, but the rate at which fuel is burnt – and therefore the amount of thrust – can be controlled by changing the amount of surface exposed to ignition during different times in the rocket's flight. This can be done by packing the fuel/oxidant mix with a hollow gap down the centre, running along the length of the rocket. Depending on the profile of this gap, which may be circular or star-shaped, for instance, the amount of exposed surface will change during the flight.

The more widespread liquid-fuelled rockets are far more complex. Typically they involve a pair of propellant tanks – one each for the fuel and the oxidant – connected to a combustion chamber through a complex maze of pipes. High-speed turbopumps driven by their own independent motor systems are used to deliver liquid propellant into the chamber through an injection system. The rate of supply can be throttled up or down depending on requirement, and fuel can be injected as a simple jet or a fine spray. Inside the combustion chamber, an ignition mechanism is used to begin combustion – this may be a jet of high-temperature gas, an electric spark or a pyrotechnic explosion. Rapid ignition is critical – if too much fuel/oxidant mixture is allowed to build up in the combustion chamber, then a delayed ignition can generate enough pressure to blow the rocket apart, a catastrophic event that rocket engineers laconically refer to as a 'hard start' or 'rapid unscheduled disassembly' (RUD).

The detailed design of a liquid rocket stage can vary a lot depending on its fuel and other requirements. Some of the most efficient propellants are liquefied gases such as liquid hydrogen, which is only stable at very low temperatures – around -253 degrees Celsius (-423 degrees Fahrenheit). Once loaded aboard the rocket, these 'cryogenic' propellants must be stored in heavily insulated tanks. Some rockets avoid the need for an ignition mechanism using 'hypergolic' propellants that ignite spontaneously on contact with each other.



2 Pump system
A turbopump system draws fuel and oxidant from the tanks at high speed and injects it into the combustion chamber.

3 Propellant tanks
The interior of each stage is filled with large propellant tanks for fuel and oxidant – fuels such as liquid hydrogen may be efficient, but they are also bulky.

4 Interstage adaptor
Rocket stages are separated by empty 'spacers' called interstages, fitted with explosive bolts that push them safely out of range before the next stage fires.

5 Ignition system
An electric spark, explosive charge or jet of hot gas ignites the fuel/oxidant mix.

6 Payload fairing
An aerodynamic case called a fairing protects the mission payload from the atmosphere during launch, then falls away in space.

7 Upper stage
Upper-stage rockets are smaller but often more complex than the lower stages, with the ability to be switched off and re-ignited at different times.

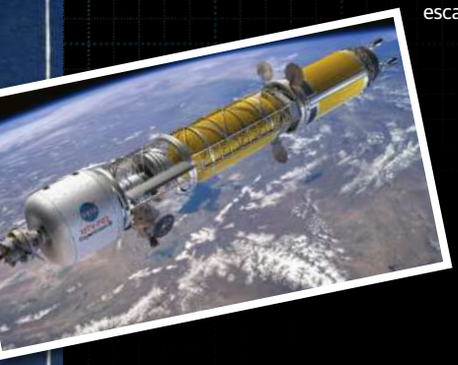
8 Combustion chamber
Fuel and oxidant undergo violent combustion, creating expanding gases that are forced out through a shaped nozzle at the bottom. This generates upward thrust in the rocket motor itself.

9 Solid rockets
Solid rockets have a simpler design, with a mix of fuel and oxidant that ignites when triggered and burns continuously until exhausted.

4 Interplanetary travel

Rockets are the key to exploring our Solar System – but how do they go from orbit to deep space?

Below: Nuclear thermal rockets are a hypothetical way of generating large amounts of thrust for sustained periods – they could one day shorten the journey time to other planets from months to weeks



The first stage of any spaceflight involves launch from Earth's surface into a relatively low orbit around 200 kilometres (124 miles) up, above the vast majority of the atmosphere. Here gravity is almost as strong as it is on the surface, but friction from Earth's upper atmosphere is very low, so if the uppermost stage of the rocket is moving fast enough, it can maintain a stable circular or elliptical trajectory where the pull of gravity and the vehicle's natural tendency to fly off in a straight line cancel each other out.

Many spacecraft and satellites travel no further than this low-Earth orbit (LEO), but those destined to leave Earth entirely and explore the wider Solar System need a further boost in speed to reach escape velocity – the speed at which they can never be pulled back by our planet's gravity. The escape velocity at Earth's surface – 11.2 kilometres (6.9 miles) per second – is about 50 per cent faster than the typical speeds of objects in LEO. It gets lower at a greater distance from Earth, and probes bound for interplanetary space are often first injected into elongated or elliptical orbits by a carefully timed burst of thrust from an upper-stage rocket, which may remain attached to the spacecraft for the rest of its interplanetary flight. In such an orbit, the spacecrafts' distance from Earth can range from hundreds to thousands of kilometres, and its velocity will also vary, reaching a maximum when the spacecraft is closest to Earth, a point called perigee, and slowing down further out.

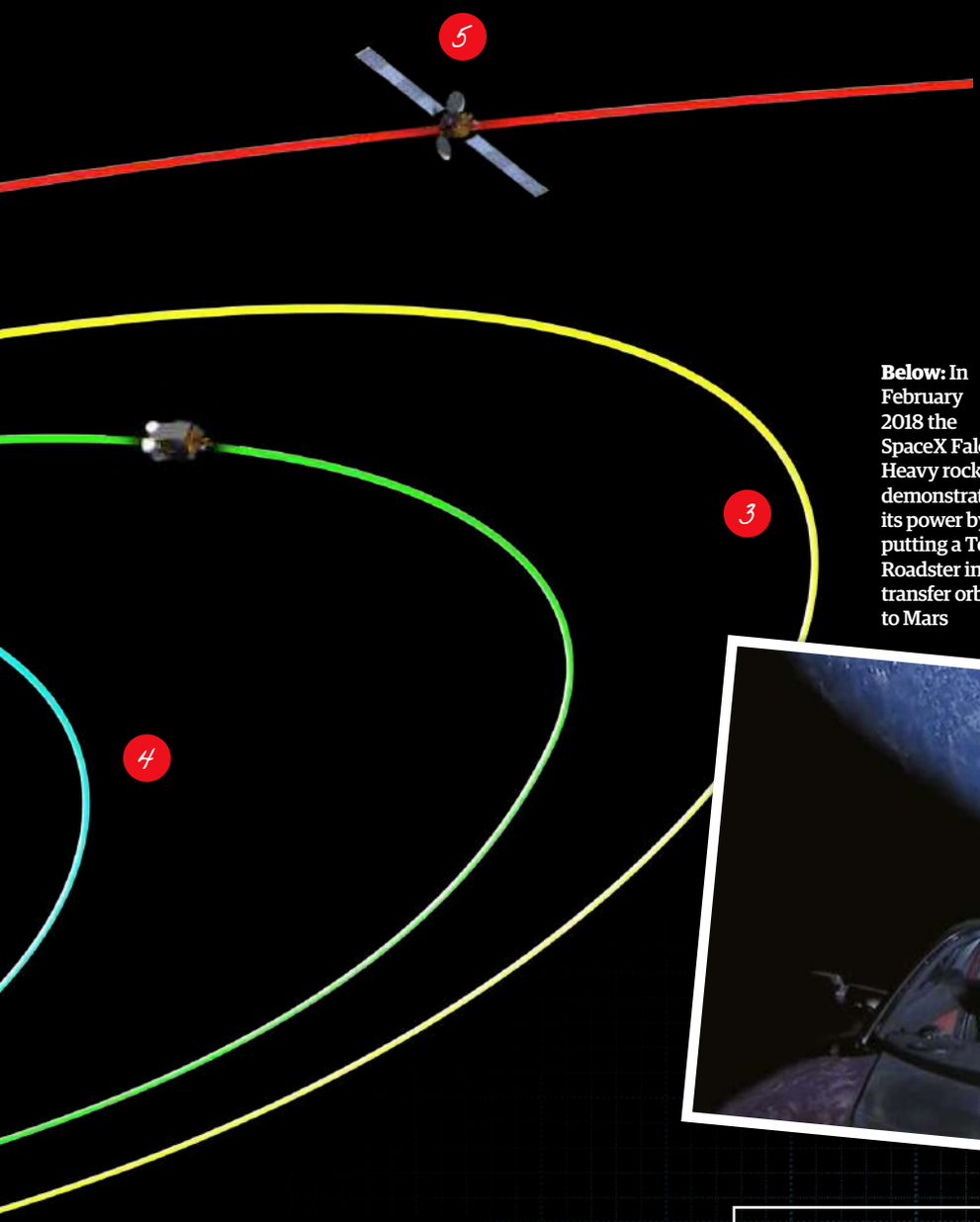
1 Low-Earth orbit
Directly after launch, a space probe usually enters a roughly circular low-Earth orbit a couple of hundred kilometres above the Earth.

2 Ellipse around the Earth
One or more precisely timed rocket burns nudge the spacecraft onto a more elliptical trajectory that varies in distance from Earth.

© NASA; SpaceX; Adrian Mann

4 *Close burn*
The Oberth effect allows a spacecraft's rockets to deliver more thrust for a set amount of fuel when it is already moving at high speed and close to Earth.

5 *Hohmann transfer orbit*
A final burn allows the probe to break free from Earth on a trajectory that looks like a spiral from our point of view, but is actually a segment of an elliptical orbit around the Sun.



3 *Picking up speed*
In an elliptical transfer orbit the probe moves more slowly at greater distance from Earth, and much more quickly around its closest approach.

Surprisingly, however, the critical rocket burn used to escape into interplanetary space is usually made when the spacecraft is near perigee. This is due to the so-called 'Oberth effect', an unexpected property of rocket equations that means a rocket is more efficient when it is moving at higher velocity. One way to understand this is that burning a spacecraft's fuel allows the engine to utilise not only its chemical energy, but also its kinetic energy, which is greater at higher speeds. On balance, the additional rocket thrust needed to reach escape velocity from a low altitude at higher speed is less than that needed to escape from a high altitude when moving at a lower speed.

Spaceflight engineers and mission planners often refer to the 'Delta-v' required to accomplish a specific flight manoeuvre, such as a change in orbit. Strictly speaking, the term 'Delta-v' means change in velocity, but engineers use it specifically as a measure of the amount of 'impulse', or thrust force over time, needed to accomplish a manoeuvre. Broadly speaking, missions are planned around a 'Delta-v budget' – how much thrust they can generate for how long using the spacecraft's onboard fuel supplies.

Sending a spacecraft from one planet to another with minimum Delta-v requirements involves injecting it into an elliptical orbit around the Sun, called a Hohmann transfer orbit. The spacecraft travels along a segment of the elliptical path that resembles a spiral track between the orbits of the two planets, and requires no further thrust along its journey. On arrival at its target object it may use gravity alone to enter its final orbit, or it may require a burst of rocket thrust in the opposite direction – usually accomplished by simply turning the spacecraft around in space and firing the motor – before it can achieve a stable orbit.

Below: In February 2018 the SpaceX Falcon Heavy rocket demonstrated its power by putting a Tesla Roadster in a transfer orbit to Mars



"Burning fuel allows the engine to utilise not only chemical energy, but also kinetic energy"

HUBBLE'S GREATEST DISCOVERIES

Join us as we take a tour of our favourite images by this iconic space telescope

Written by Laura Mears



INTERVIEWBIO

Dr Mario Livio

Senior astrophysicist at the Hubble Space Telescope Science Institute

Dr Mario Livio is an astrophysicist specialising in exciting stuff like black holes, neutron stars, white dwarfs and supernova explosions. He has worked with Hubble at the Space Telescope Science Institute since 1991 and has published over 400 scientific papers and five popular science books.

The Hubble Ultra-Deep Field

The Hubble Space Telescope has celebrated over 30 years in space. Over the past three decades, this astonishing feat of engineering has made more than a million observations, provided the data for over 10,000 scientific publications and has given us a breathtaking window out into the far reaches of the universe from its position beyond the haze of our atmosphere.

Hubble was the brainchild of American astrophysicist Lyman Spitzer Jr and its construction took almost a decade, completed in 1985. However, its journey into space was complicated. Its launch was delayed by the Challenger disaster in 1986, which claimed the lives of seven astronauts and by the time it arrived in orbit in April 1990, its first images were blurry. To the dismay of the team, the carefully crafted 2.4-metre (94.5-inch) mirror had a spherical aberration, a microscopic fault that prevented the light from being properly focused.

Hubble was designed to be able to dock with the Space Shuttle, allowing repairs and upgrades to be performed in space. A series of corrective mirrors were installed by intrepid astronauts in a week-long mission in 1993, acting like a pair of glasses and bringing the light into focus. Since the repair, the telescope has been upgraded on a further four occasions and has gone on to capture thousands of stunning, high-resolution and iconic images.

Hubble is responsible for some of the biggest scientific discoveries of the space age. It showed that dark energy is accelerating the expansion of the universe and allowed scientists to pinpoint its age to between 13 and 14 billion years. And it has found that there are supermassive black holes at the centres of almost all galaxies.

In its 30 illustrious years in space, Hubble has taken some of the most breathtaking images of the cosmos and in the process, this amazing machine has captured the hearts and minds of the adoring public like no other space telescope has done before.



The galactic rose

This stunning image was released as part of Hubble's 21st birthday celebrations in 2011. The cosmic rose at its centre is formed by two interacting galaxies known together as Arp 273. The image was captured using the Wide Field Camera 3 (WFC3) and filters were used to distinguish between ultraviolet, blue and red light. A small galaxy called UGC 1813, viewed side-on from the Earth, forms the stem of the rose while the flower itself is a galaxy known as UGC 1810, which is five times bigger. Astronomers believe that a past collision pulled the larger galaxy into its distorted, petalled shape. The ring that encircles UGC 1810 indicates that the smaller galaxy burst straight through as they collided, passing off-centre through the plane of the spiral and pulling its arms into a ring. As a result of the collision, the centre of the small galaxy has lit up and the larger galaxy is studded with massive hot blue stars born out of the chaos. At the top-right of the larger galaxy, there is another visible mini-spiral, along with a blue burst of young star activity.

The Sombrero galaxy

This incredibly detailed image of M104 was captured by the Hubble's Advanced Camera for Surveys. It is one of the biggest Hubble images ever taken, and it was stitched together from six separate exposures and used red, green and blue filters to create a true-colour representation.

The galaxy, nicknamed the 'Sombrero galaxy' after its wide, flat shape, is one of the most massive objects in the Virgo cluster. It was originally thought to be a star, but it is moving away from us at speeds of over 1,127 kilometres (700 miles) per second and it is now known to measure 50,000 light years in diameter. It is almost the same age as the Milky Way, with globular clusters dating back 10 to 13 billion years.

In the very centre is a second disc, which appears at an angle to the main disc of the galaxy. It emits bright X-ray radiation and is thought to belong to a supermassive black hole measuring one billion solar masses.



INTERVIEW

"This visually stunning galaxy is about 28 million light years from Earth. We view it almost edge-on. The main reason I like this image is that Hubble has captured the dust lanes in the galactic ring that surrounds the central bulge with such a resolution that the image looks almost three-dimensional. Around the galaxy, you can see a collection of between 1,000 and 2,000 globular star clusters. This is about ten times more than the number of clusters that surround the Milky Way."



The auroras of Saturn

In 2003, Hubble collaborated with the Cassini spacecraft to monitor the auroras in Saturn's atmosphere. Hubble's Advanced Camera for Surveys captured the visible light images of the outline of the planet, and its Space Telescope Imaging Spectrograph revealed the ultraviolet glow of the auroras as they moved through the atmosphere. What they saw were auroras that last for days on end and glow brightly throughout.

With Cassini's help, we know that these auroras are created by pressure changes in Saturn's atmosphere. As the solar wind increases, the auroras brighten and shrink in diameter.

Although the aurora seems to glow a bright, icy blue in this image, on the surface of Saturn the spectacle would appear to be quite different. As the blueish ultraviolet light hits the atmosphere, it excites hydrogen atoms making them glow red. On Earth, we see something similar, except that in our atmosphere of nitrogen and oxygen, the dominant colours would be green and blue.



INTERVIEW

"These images in ultraviolet light capture Saturn's auroras as they change over a few days. Auroras are the result of charged space particles colliding with the planet's magnetic field, leading to flashes produced by gas in its atmosphere. The emission is in the form of radio waves and ultraviolet light. An increase in the intensity of the emission is accompanied by the emission ring shrinking. This particular behaviour is different from those observed in the auroras of both the Earth and Jupiter."

Jupiter's stormy spots

Hubble's Wide Field Planetary Camera 2 has trained its eye on Jupiter, watching carefully as storms rage across the equator. The enormous storm that is Jupiter's Great Red Spot has achieved worldwide fame, persisting in the Jovian atmosphere for 200 to 350 years, but it is not alone. This image captured in 2008 shows its two smaller companions. The largest, Red Spot Jr, was discovered in 2006, but the third, dubbed Baby Red Spot, was new. They both started life as white spots and turned red as material was lifted high above the methane atmosphere, exposing it to ultraviolet light. Shortly after this image was taken, Hubble watched as Baby Red Spot became caught up in the vortex of its big brother and vanished, providing a potential explanation as to how the great storm continues to gather momentum even after all this time. Since it was first measured by the Voyager spacecraft in the 1970s, the Great Red Spot has shrunk dramatically and Hubble's newer Wide Field Camera 3 continues to keep watch.

Comets, stars and galaxies

The star of this image isn't actually a star, but the streaking comet ISON, snapped by Hubble as it made its final journey towards the Sun. As it travelled inwards the temperature rose, leaving a tail of evaporating material in its wake. ISON was known as a sungrazing comet, and in December 2013 it broke apart as it faced searing heat and came within 1.9 million kilometres (1.2 million miles) of the surface of the Sun.

At first glance, the background appears to be studded with stars, but a closer look reveals a sea of galaxies. Captured by the Wide Field Camera 3, this incredible image is a combination of separate exposures, and Hubble reveals an amazing contrast of depth. The comet was just a few hundred million miles from the Earth, the nearest stars in the picture are 60,000 times more distant and the closest galaxies are more than 30 billion times farther away.

A cosmic cave

This incredible nebulous cave has been carved out by some of the most massive stars in the known universe and in this image, stitched together from several separate pictures captured by both the Wide Field and Planetary Camera 2 and the Advanced Camera for Surveys, the architects of this grand cosmic palace are revealed.

The bright stars at the top of this image are part of the cluster known as Pismis 24 and are some of the brightest and most massive stars in space. Their combined emissions have sculpted enormous structures in the NGC 6357 nebula below, with a combination of gravity, interstellar wind, radiation pressure and magnetic fields coming together to shape vast pillars into the gas cloud. At the bottom of the image, nestled inside the nebula itself, is another massive star, which is carving out an enormous cavern in the glowing hydrogen gas.

The stars that have produced this incredible spectacle are truly enormous, but Hubble has revealed new clues about their structure. Once thought to be one of the most massive stars in the known universe, it is now known that the largest star in the cluster is a binary, containing two smaller stars.



INTERVIEW

"This image shows the nebula NGC 6357, being irradiated by the massive stars in the cluster Pismis 24. The nebula is at a distance of about 8,000 light years from Earth. One of the bright stars in the Pismis cluster was once thought to be more than 200 times the size of the Sun. However, Hubble's sharp vision has shown that the object is really composed of two stars, about 100 solar masses each. The intense radiation from the star cluster is not only causing the nebula to glow, but is also eroding the gas and dust, leaving only the densest parts as pillars pointing towards the star cluster."



The perfect spiral

This incredible image of the spiral galaxy M74 is the fruit of a combination of data captured over two separate years by The Advanced Camera for Surveys and has been combined with images captured by two ground-based telescopes to create a high-resolution view of the structure of a spiral galaxy. From our position on Earth, M74 is visible almost head-on, creating an incredible portrait of the intricate swirls that make up spiral galaxies like our own, albeit on a smaller scale.

M74 is an almost-perfect, two-armed spiral with dark dust lanes twisting outwards from its nucleus. Filters used on the camera reveal blue, visible and infrared light, highlighting chains of bright young stars that adorn its edges. Hubble has also picked out pockets of irradiated hydrogen gas, glowing pink as the ultraviolet light emitted by these hot young stars excites the molecules, providing an ideal environment for star formation.



INTERVIEW

"The galaxy M74 is at a distance of about 32 million light years from Earth and contains about 100 billion stars. It is a spiral galaxy, which means that its structure is that of a pancake-like flat disc. We are viewing the galaxy face-on, so that the spiral structure, which is a consequence of density waves in the galactic disc, is beautifully visible. New stars are being born in the spiral arms and they heat up the gas and cause it to glow. Three exploding stars, known as supernovae, have been detected in M74. One in 2002, one in 2003 and one in 2013."



Hot new stars

This image, captured by the Advanced Camera for Surveys, shows a nebulous star forming in a region nestled inside the Small Magellanic Cloud, a dwarf galaxy 200,000 light years from Earth. At the centre are the hot young stars of the NGC 602 cluster. They are just 5 million years old and are still surrounded by the dust and gas from which they were formed, but their energetic outpourings have blown an enormous hole in the cloud. They are gradually eroding away at the gas, leaving behind vast pillars that point back inwards towards the source and in the turbulent environment amongst the ridges, more new stars are beginning to form, inching outwards as the cloud is gradually blown away. The incredible resolution of Hubble's camera also reveals background galaxies, including a face-on spiral just above this text.

The centre of the galaxy

In 2008, Hubble teamed up with the Spitzer Space Telescope to peer right into the centre of the Milky Way. In the process, it orbited the Earth 144 times and made 2,304 separate exposures that were stitched together to build this stunning mosaic. Hubble's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) were able to reveal objects around 20 times the size of our Solar System, producing the sharpest infrared image ever made of the core of the Milky Way. It revealed massive stars spewing strong stellar winds, sculpting the surrounding gas and showed the glow from ionised hydrogen in the vicinity. The image was laid over a colour survey, completed by the Infrared Array Camera on board the Spitzer Space Telescope, which although only about one-tenth of the resolution of Hubble's image, separates the different wavelengths of infrared light by colour.

A delicate spiral

This delicate spiral galaxy is just 46 million light years away and was captured by Hubble's Wide Field Camera 3 (WFC3) in 2010. Four different filters were used to reveal its composition. At the centre is a yellow-white nucleus, lit by the glow of middle-aged stars and surrounding them are tight, delicate spirals composed of dark dust lanes studded with younger blue star clusters. NGC 2841 is a massive spiral galaxy and at 150,000 light years in diameter is larger than the Milky Way, but star formation within the delicate spirals has slowed. The energetic youngsters have blown most of the surrounding gas away, halting new star birth in their immediate vicinity. Pockets of pink star forming regions are still visible but overall this delicate-looking galaxy is relatively quiet compared to other spirals like our own.



The butterfly nebula

This nebulous butterfly is the aftermath of the death of a star five times the size of our own Sun and is one of the first images to be captured by the Wide Field Camera 3 (WFC3), installed in May 2009. The star at the centre is shrouded in a ring of thick dust, generated after the star swelled to become a red giant. The wings formed later and were shaped by extreme stellar winds as the central star sped up, covering an expanse of space measuring more than two light years across. Filters on the camera allow the constituent gases of the nebula to be picked out.



Pillars of creation

Found within the famous Eagle Nebula, some astronomers think this cosmic cloud has already been blown away by a nearby supernova. But, because of its distance from Earth (7,000 light years), we won't see this for another 1,000 years.



INTERVIEW

"I am certainly proud to have been a part of this fantastic scientific endeavour"

How did you get involved with Hubble?
"Shortly after its launch in 1990, I was contacted by a colleague that was already at the Space Telescope Science Institute (the institute that conducts the scientific programme of Hubble) and he asked me whether I would consider coming to work at the Institute. I had visited it already in 1986 and hence was somewhat familiar with the organisation and I knew quite a few of the astronomers there. So after a brief hesitation, I said I would definitely consider it."

Hubble got off to a shaky start: what was the feeling at the Space Telescope Science Institute when the flaw was discovered?
"I was not yet at the Institute when the spherical aberration of the mirror was discovered, but I was absolutely shocked to hear about it. When I eventually decided to come to the Institute in 1991, a few of my colleagues were telling me that I must be crazy to come work with a flawed telescope. There was indeed a serious risk, since at that point we didn't know whether it could be corrected."

At the time, did you anticipate that Hubble would go on to be such a huge success?
"Absolutely not. At that time, I feared that Hubble may be remembered as one of the biggest scientific failures. And one that could potentially jeopardise the entire concept of big, ambitious science. There was the danger that people would use the Hubble example to argue that too complex scientific missions are doomed to fail."



How did the mood change after it was fixed?
"One can hardly describe it. The feeling of elation was similar perhaps to that felt after the birth of a new child. The drama added, of course, to the iconic status of this telescope. This was an amazing demonstration of what can be achieved through the ingenuity of scientists and engineers and the courage of astronauts."

What do you think is the most iconic image captured by Hubble and which one is your personal favourite?
"There is little doubt that the Eagle Nebula is Hubble's most iconic image. We have re-observed that region in high definition as part of the 25th-anniversary celebrations. The new image is breathtaking. I personally like very much the image we call 'Mystic Mountain', which also shows pillars of gas and dust in which new stars are being born."

What were you hoping to see in the Hubble Deep Field images?
"The various Hubble Deep Fields have not only shown us the universe at its infancy, when it was less than 500 million years old, while its current age is 13.8 billion years, they have also given us the cosmic history. For instance, we now know the rate at which the universe as a whole has been forming new stars, throughout its entire history. By showing us thousands of galaxies in an area of the sky similar to that you would see through a drinking straw, the Deep Fields have visually demonstrated to us the smallness of our physical existence, compared to the vastness of space. No one knew exactly what to expect from the Deep Fields, but they turned out to be a demonstration of cosmic archaeology at its best. "

What is it about Hubble that has captured the public imagination?
"A few elements have combined to make Hubble almost unique in the history of science. Hubble has brought the excitement of discovery, which used to be the province of only scientists, into the homes of people all across the globe. The drama that was associated with the flaw in the mirror and its spectacular repair has also added to Hubble's popularity – this was the 'telescope that could'. The incredible servicing missions by shuttle astronauts also captured the imagination. Finally, Hubble's longevity, 30 years of outstanding scientific results and the unbelievable images, some of which have been dubbed by an art writer as "the most remarkable works of art of our time."

What does the future look like for Hubble?
"We hope very much that Hubble will continue to operate at least till 2020, which will allow it a few years of overlap with the James Webb Space Telescope. If the telescope will still be scientifically productive [in the 2020s], I hope that it will be kept even beyond that. Eventually, a propulsion module will be attached to the telescope, directing it into the ocean. However, I am convinced that Hubble will still make important discoveries in the coming years. I am certainly proud to have been a part of this fantastic scientific endeavour."

© NASA

The space agency celebrates over six decades of triumphs and tribulations. We highlight some of its best moments

Written by Ian Evenden

"The Hubble Space Telescope mission is clearly one of NASA's most internationally celebrated achievements. The genius of putting a telescope above Earth's blurring atmosphere has opened our eyes to a universe brimming with billions of galaxies, colourful star-forming nebulae and mysteries of dark matter and dark energy. Hubble is also revealing incredible activity in our own Solar System, and rich atmospheres of planets orbiting other stars, something never even envisioned when Hubble was first launched. The mission's success shows the power of NASA's diverse strengths working together, most notably through the several heroic astronaut servicing missions to Hubble. These have enabled the telescope to stay at the very forefront of scientific discovery even decades after launch, and we anticipate many good discoveries from Hubble for years to come."



Dr Jennifer Wiseman
Hubble Space Telescope senior project scientist
NASA's Goddard Space Flight Center



Explorer programme

Explorer 1 was the first US satellite to go into orbit around Earth in 1958. Although it was first a military project, NASA took over the programme with 1959's Explorer 6. The Explorer programme is ongoing.

Modern Explorer missions are split into two main classes, Small and Medium. Medium missions were originally designed to be launched on a new, smaller, cheaper rocket, but this was never developed, and a modified Delta II is used instead. Examples include 1997's ACE, which is still operational and studying the solar wind's particles, and WISE, launched in 2009.

Small missions are even smaller, with a mission cost cap of $165m (around £130m) in 2017. Examples include the Sun-observing IRIS telescope, which has discovered plasma jets and tornadoes in the Sun's chromosphere.

Explorers will continue into at least 2024, and there's no reason to believe NASA is going to stop there.



Apollo programme

When Kennedy made his famous speech, NASA had yet to put an astronaut in orbit. Development of the Saturn rocket launch system was accelerated, with the first unmanned test flight of a complete Apollo system taking place in February 1966.

Apollo 1 would follow, but suffered a disastrous fire during a launch rehearsal that killed all three astronauts on board. Further unmanned tests were carried out before Apollo 7 blasted off in October 1968, successfully orbiting the Earth for 11 days.

Apollo 8 would orbit the Moon in December 1968, returning TV pictures of the Moon's surface. Apollo 9 and 10 tested spacesuits and got closer to the Moon's surface than 8 had so that in the summer of 1969, all was set for landing.



Project Mercury and the Seven

It took less than a year for the US to catch up after the USSR put Yuri Gagarin into orbit on 12 April 1961. Project Mercury was already in existence, and succeeded in a sub-orbital flight, carrying Alan Shepard, on 5 May 1961. John Glenn would follow, orbiting the Earth three times on 20 February 1962.

20 unmanned flights were completed, of which three were launched after the manned flights. Some also carried animals, including a chimpanzee called Ham who was recovered from the Atlantic Ocean with no ill effects.

Mercury astronauts would eventually rack up 53 hours, 55 minutes and 27 seconds in orbit over six flights, and became the backbone of future NASA missions.

Apollo 11

The USSR had plans to land cosmonauts on the Moon in September 1968. Unfortunately for the Soviet space programme, its senior rocket engineer died in 1966, and this, along with a lack of funding, led to the project being delayed.

Neil Armstrong, Buzz Aldrin and Michael Collins reached the Moon on 19 July 1969, entered orbit and prepared to land, making history for the Apollo programme and crowning the US the winners of the long-fought Space Race.





Pioneer

The first spacecraft to explore the Moon were launched between 1958 and 1960. Pioneer 5 was fired towards Venus, and confirmed the existence of interplanetary magnetic fields.

Pioneers 6, 7, 8 and 9, launched by NASA between 1965 and 1968, orbited the Sun at distances between 0.8 and 1.1 AU, and were able to make detailed measurements of the solar wind.

Pioneer 10, launched in March 1972, was the first spacecraft to traverse the Asteroid Belt, and took a close approach to Jupiter in December 1973. Pioneer 11 went one better and encountered not only Jupiter, but Saturn as well. Launched in April 1973, it flew past Jupiter in late-1974, taking detailed images of the Great Red Spot. It reached Saturn in September 1979, passing just 20,921 kilometres (13,000 miles) from the gas giant.

Apollo 13

While Soviet interest in Moon landings dried up after Apollo 11, NASA kept on going. Apollo 12 made a successful landing in November 1969, despite lightning striking the launcher 36 and 52 seconds into its flight.

Apollo 13 launched in April 1970. Launch and module separation was successful, and the astronauts Jim Lovell, Jack Swigert and Fred Haise were 56 hours into the three-day trip to the Moon when they heard a bang and noticed their oxygen supply began to drain – they were forced to abandon their mission.

They retreated to the lunar module, using it as a lifeboat, and turned off all unnecessary electrical equipment. They continued to orbit the Moon, using its gravity to change their trajectory. The crew returned safely to Earth on 17 April 1970.





Viking

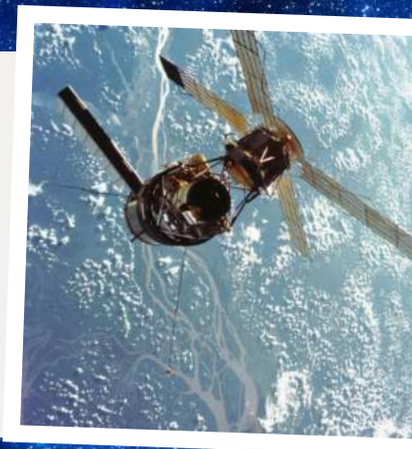
NASA returned to Mars in 1976 with Viking, a pair of probes designed to both orbit and photograph the planet, and this time to land. The USSR beat the Americans in landing a probe on another planet, having put Venera 3 on Venus in 1966.

Data from Mars was valuable, and Viking even carried experiments to look for life. While rovers explored the surface Viking's two orbiters continued their work above, taking more photos and acting as communications relays for the landers.

Skylab

Skylab was launched in May 1973, although it can't claim to be the first space station to orbit the Earth – the USSR got there first in April 1971 with Salyut 1.

Skylab was assembled in one piece on Earth and launched as the final mission of the Apollo programme's Saturn V rocket. The station's three astronaut crews were ferried to the station in Apollo command modules launched on smaller rockets.



Mariner

Mariner sent robotic probes to the rocky planets between 1962 and 1973, and with each new mission we learnt more about our closest planetary neighbours.

NASA probed Venus' thick atmosphere with radio waves and sampled its magnetic field, and was able to confirm Venus was a hot, high-pressure world.

Mariner 9 was the first spacecraft to orbit another planet, photographing 85 per cent of the Martian surface, unveiling Olympus Mons along with canyons and craters, adding to the data and images from previous missions. Mariner 10 passed both Venus and Mercury on its journey.





"When I think about NASA's greatest achievements, I think about all the things NASA does to push the boundaries of impossible. Landing people on the Moon, sustaining human life in space and discovering the secrets of the cosmos through our awesome space telescopes, NASA helps us answer questions about our place in the universe, and what it means to be human."

Dr Amber Straughn
Astrophysicist
NASA's Goddard Space Flight Center



Voyager

An offshoot of the Mariner program, the twin Voyager probes were launched to the outer Solar System in 1977. Relying on a planetary alignment that occurs once every 176 years, the spacecraft were able to use the gravity of each planet they visited to align their trajectory to the next one.

Voyager 2 launched first, its mission to fly past Jupiter, Saturn, Uranus and Neptune. Voyager 1's route through the Solar System was shorter and faster, allowing it to investigate Saturn's moon Titan at the cost of being flung out of the Solar System without the chance of visiting other planets.

Voyager 1 overtook its twin in December 1977, passing Jupiter in March 1979 and Saturn in November 1980, flying past Titan as it entered the system.

Space Shuttle

The hugely famous and successful Shuttle Transportation System first flew in August 1977, but didn't undertake its first crewed mission until April 1981. Out of 135 launches, two ended in failure with the Challenger and Columbia disasters sadly taking 14 lives.

The Shuttle programme would carry more than 350 astronauts to orbit. The programme enabled the construction of the ISS and Hubble; saw the first American woman in space, Sally Ride; the first untethered spacewalk; the first refurbishment of an orbiting satellite; the first launch of an interplanetary probe from orbit (Magellan); the first non-astronaut crew member... the list goes on.





"NASA's greatest accomplishment is being able to do things that no one else has ever done. NASA has sent humans to the Moon, created and operated the world's first reusable spacecraft and now transformed into an agency that is not only able to develop a spacecraft to take humans to Mars, but also support multiple commercial aerospace companies in their human spaceflight programmes to explore space."

Tom Engler
Director of the center planning and development office
NASA's Kennedy Space Center

Hubble



Launched in April 1990 aboard Discovery, Hubble's 547-kilometre (340-mile) altitude puts it well outside Earth's atmosphere, higher than Shuttles usually operate. Only Discovery's 1997 mission to boost the telescope's orbit has gone higher.

Along with producing beautiful images of the universe it has accurately measured the distances to Cepheid variable stars, allowing a more accurate measurement of the expansion of the universe, which also allows a more accurate estimate of its age.

Galileo

Galileo arrived at Jupiter orbit in December 1995, having released an atmospheric probe five months earlier. The probe flew ahead and survived for 57 minutes as it descended through Jupiter's cloud tops. It discovered Jupiter was denser, hotter and more radioactive than expected, with less helium than predicted and fewer cloud layers.

Meanwhile, in orbit, Galileo was able to confirm volcanic activity on the moon Io, find evidence for a liquid subsurface ocean under Europa, discover a thin atmosphere on three moons, and detect a magnetic field on the moon Ganymede, the first moon to be shown to have one.



NASA's fleet of rockets

During the Cold War, the political posturing of the Space Race was underpinned by military technology. The rockets used to propel men and machines into orbit were essentially missiles, and whoever had the largest and most successful missiles could consider themselves the winner.

NASA turned to the Saturn family, and chose the most powerful configuration available: the Saturn V. It remains the only launcher to take humans beyond Earth orbit.

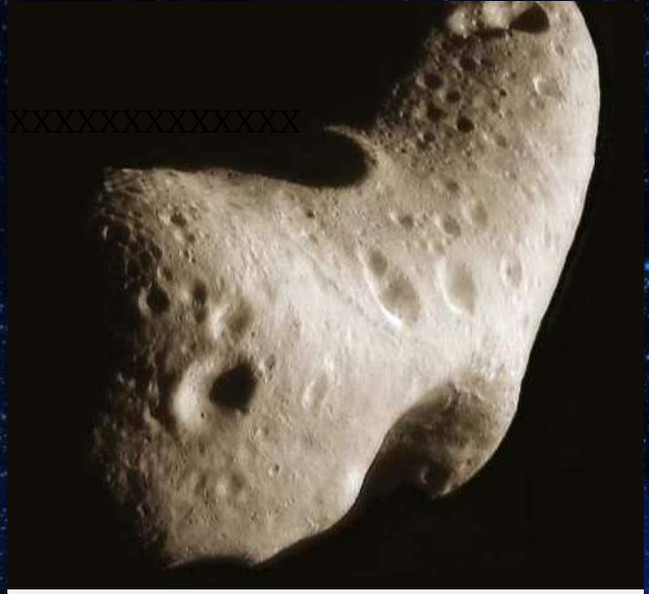


Hubble repair mission



Hubble's giant mirror was very nearly its downfall. Initial images from the telescope were disappointing, and the fault was traced to the mirror's grinding and polishing process – one lens used to check the shape was out of position.

The response to this was a 1993 servicing mission, STS-61, that had been scheduled to go to the telescope for maintenance anyway. An instrument called the Corrective Optics Space Telescope Axial Replacement or COSTAR was added to Hubble, replacing one of its original instruments. As corrective optics, it was essentially giving the telescope glasses.



NEAR Shoemaker

Planets are quite big, but probes have managed to miss them with regularity, so when you're targeting something as small as an asteroid, the difficulty increases.

Near Earth Asteroid Rendezvous (NEAR) was launched in February 1996, named in honour of planetary scientist Eugene Shoemaker. Its primary target was Eros, an S-type (stony) asteroid that orbits the Sun on a path that takes it through the orbits of both Earth and Mars.

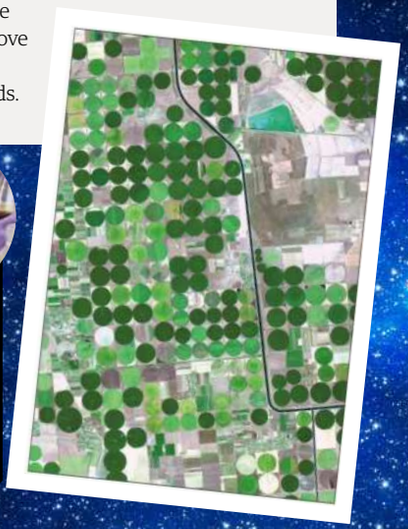
Following a year of orbital observations, NEAR landed on the asteroid, lasting a further 16 days before being shut down. NEAR was the first in NASA's Discovery program, designed as low-cost launches that can be put together in less than three years.

NASA's Earth observations

NASA achievements don't always look outwards to deep space or the Solar System... sometimes they are looking back at Earth.

The Earth Observing System (EOS) began in 1999 with the launch of ACRIMSAT, which measured the energy being received from the Sun. It was able to view the 2004 transit of Venus and measure the approximate 0.1 per cent reduction in output caused by the planet crossing the solar disc.

There have been 26 satellites in the EOS constellation, not all active at the same time, studying things such as the ozone layer, the weather, Earth's magnetosphere and ocean surface currents. EOS is the centrepiece of NASA's Earth Science research, hoping to improve the prediction of weather and climate change, as well as enabling rapid responses to natural hazards.





"NASA's discoveries of the chemical building blocks of life on early Mars will help shape the search for life on the Red Planet. The coming decades will be exciting as we continue to explore and begin to develop the next generation of life-detection instruments."

Dr Mary Beth Wilhelm
Research scientist at NASA's Ames Research Center in Silicon Valley



Ed White's spacewalk

Project Gemini was NASA's second manned spaceflight programme, slotting in between Mercury and Apollo. Its two-man crews never went beyond low-Earth orbit, but their work laid the foundations for Apollo's trips to the Moon.

Gemini 4 was the second manned launch of the system and saw Ed White and his commander James McDivitt become the first crew to spend multiple days in space. This was also the first spacewalk, with White tethered to the capsule and using a handheld oxygen cylinder to provide thrust. The walk lasted 23 minutes, with White at the end of an eight-metre (26.2 foot) tether.

New Horizons

In the nine years it took New Horizons to reach it, Pluto was downgraded from a planet to a dwarf planet, but this made no difference to the mission. It passed through the Pluto system in July 2015, accumulating so much data that it took 15 months to send it all back to Earth.

Pluto was a fuzzy, indistinct world even when imaged by Hubble, but thanks to New Horizons it snapped into focus: a red-and-white world largely covered in nitrogen ice, so cold that water takes the place of rock. The probe discovered a thin atmosphere of nitrogen, methane and carbon monoxide, before passing through the system and into the cold, mysterious Kuiper Belt beyond.





Being founded as a civilian agency

It would have been so easy in 1958, at the height of the Cold War, with Sputnik 3 being launched, Castro making revolutionary attacks in Cuba and Khrushchev taking power in the USSR, for space exploration to be kept as a military project. But US President Eisenhower and the 85th United States Congress thought differently, and an act was passed creating a new civilian agency – NASA – that would have a scientific and technological role, as well as encouraging cooperation between nations.



Parker Solar Probe

The Parker Solar Probe is getting closer to the Sun than ever before, with an ambitious plan to 'touch' the outer corona. The probe is designed to be highly automated as radio contact will take eight minutes, and the spacecraft will need to react more quickly to sudden changes in the Sun's output.

Its goals are to track the flows of energy within the Sun that heat its corona and power the solar wind. It hopes to determine the structure of the Sun's magnetic field, and determine how energetic particles are accelerated. Its orbits around the Sun will cross those of Mercury and Venus, and the probe will make seven flybys of Venus as it shrinks its orbit to get closer to the Sun.

Mars Science Laboratory

Also known as the Curiosity Rover, the Mars Science Laboratory launched in November 2011. It is preparing the way for a manned expedition to Mars, investigating the planet's habitability, studying its climate and geology and measuring its surface radiation.

It landed in the Gale Crater, a depression caused by a meteor strike that at one point in its history was probably a lake. The crater was selected for both prior evidence of past water on Mars, and the richness of its mineral deposits. Curiosity has an onboard laser to blast samples of rock and soil, analysing the vapour that results.





Cassini-Huygens

The probe's objectives were to map the 3D structure of Saturn's ring system, determine the composition and history of each moon, study the atmospheres of both Saturn and its moon Titan and photograph everything it could.

Cassini provided the most detailed colour images of the giant planet yet seen, discovering atmospheric circulation in the impenetrable cloud banks.



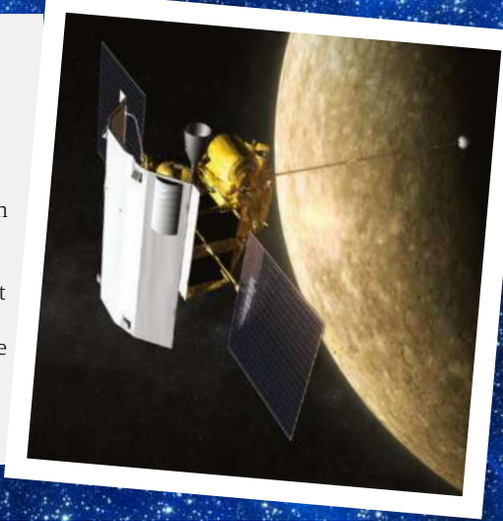
"The Space Shuttle ranks as one of NASA's greatest technical achievements. As the most complex machine designed, built and flown by human beings, it enabled hundreds of advancements in human, Earth and space sciences over its 30 years of service. It remains one of the best examples of what great things we can accomplish when we work together towards a common goal."

Matt Melis
Aerospace engineer at NASA's Glenn Research Center

Messenger

Mercury, thanks to its position relative to the Sun, is a difficult planet to study. MESSENGER had two solar panels that extended like wings from its sides and weighed more than a ton at launch - half of that was fuel. Inside, however, it was packed with instruments, and was protected by a highly reflective sunshade from the intense light and heat it would experience. It completed its mission in April 2015.

Once at Mercury, MESSENGER was able to confirm that there are water ice and organic compounds inside craters at its north pole, something suspected from Earth-based observations.





The International Space Station

A joint project between NASA, Canada, Russia, Europe and Japan, the International Space Station began life in November 1998 with the launch of its first module, Zarya, on a Russian Proton rocket. A Space Shuttle mission blasted off two weeks later carrying a second module, the American Unity module, and the two were connected together by spacewalking NASA astronauts.

From there, the station has bloomed to contain 15 modules and an Integrated Truss Structure to hold them all together. Continuously occupied for almost 18 years since the first crew arrived in November 2000, astronauts and space tourists from 18 nations have stepped aboard. The ISS provides a platform to test spacecraft technologies that may one day take humans back to the Moon or to Mars, along with prototype modules. The station houses laboratories operated by NASA, the ESA, Russia and Japan, as well as a seven-windowed observatory known as the Cupola, used to view the Earth and approaching spacecraft.

10 Spacecraft that changed the World

We take an in-depth look at the past, present and future of the world's greatest spacecraft, from the early pioneers to the modern marvels that have explored the Solar System

Written by Nigel Watson



1 Apollo 11 Lunar Module

The first manned spacecraft to land on the Moon

To perform the first Moon landing, the Apollo 11 mission used two very different spacecraft. The first was the pressurised, conical-shaped Command Module that served as the main living quarters. It was attached to an unpressurised Service Module containing the main rocket engine and propellant.

At launch, the Apollo 11's Command and Service Module (CSM) was mounted above the Lunar Module (LM) on top of the Saturn V rocket. When they moved out of Earth orbit, the CSM separated itself and turned around to attach to the docking port on the LM.

On 20 July 1969 at 21:17 (BST), Neil Armstrong and Edwin 'Buzz' Aldrin touched down on the Sea of Tranquility, and deployed exploration equipment from a bay on the side of the Descent module.

On leaving the Moon, the Ascent stage's own rocket motor blasted off the Descent stage that remained on the moon. After docking with the CSM, the Ascent stage was jettisoned and left to crash back on the Moon. Prior to re-entry, the Service Module was jettisoned, and after re-entry, the Command Module parachuted down to a splashdown in the sea.

2 Saturn V

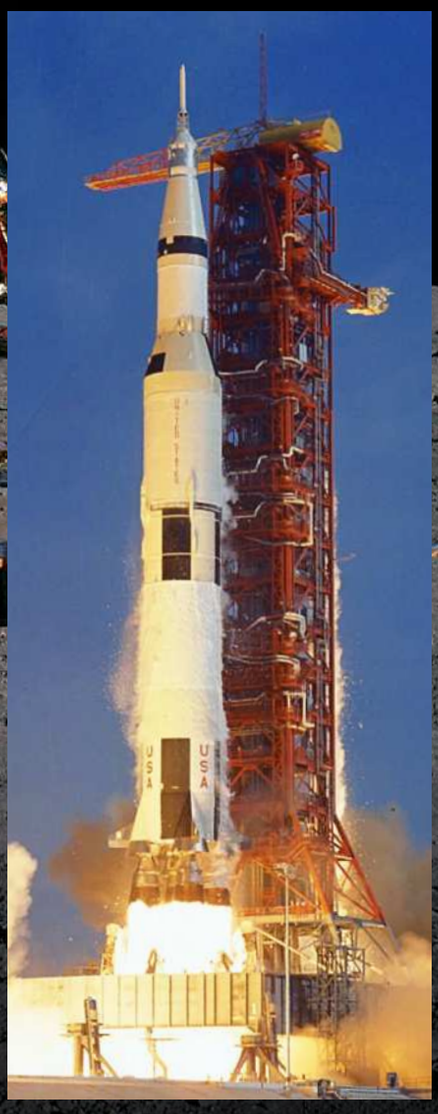
The most powerful rocket of all time

The mighty three-stage Saturn V rocket towered to a height of 110.6 metres (363 feet) and weighed 3 million kilograms (6.7 million pounds) fully fuelled. It was constructed under the direction of Dr Wernher von Braun, the German rocket pioneer, at the Marshall Space Flight Center, Huntsville, Alabama.

A workforce of 5,000 people took four months to fit the Saturn V's rocket stages together in the Vehicle Assembly Building at the Kennedy Space Center, Florida.

Altogether, 15 Saturn V rockets were built, and even today, they remain the biggest rockets ever put into service. The closest to it was the Soviet Union's N1 Moon rocket that measured 105 metres (344 feet) tall, but it exploded on all four attempts to launch it.

In comparison, the Space Shuttle was only 56 metres (184 feet) tall. Only the Ares I, at 94 metres (308 feet) tall, has come close to the size of the Saturn V, but it was cancelled due to NASA budget cuts.

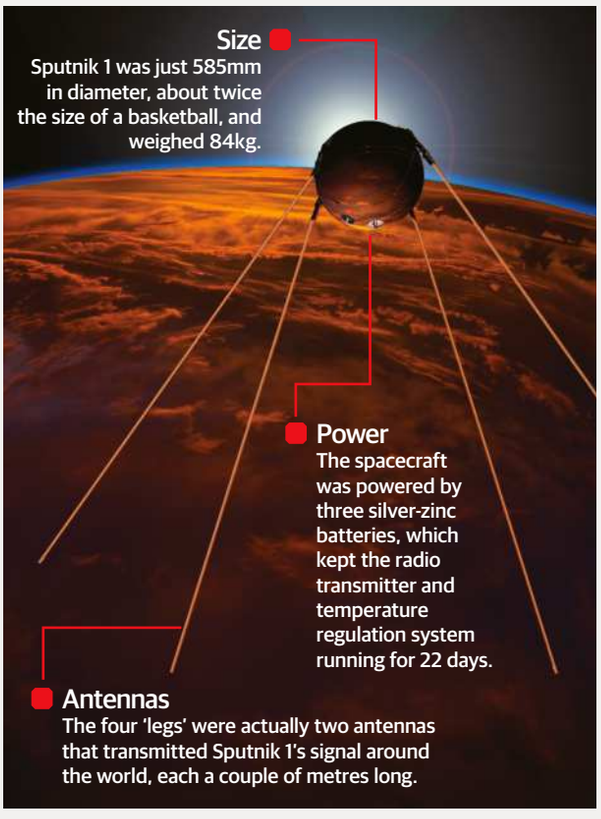




3 Vostok 1

The original manned spacecraft

Vostok 1 was the spacecraft that took the first ever human to space, Yuri Gagarin, on 12 April 1961. Although troubled by performance issues, Vostok 1 was a technical marvel. Never before had a vehicle been able to take a human to orbit and return them intact, and therefore Vostok 1 was almost entirely autonomous to prevent any human error. Gagarin could only take control in an emergency, unlike Alan Shepard a few weeks later in the Freedom 7 spacecraft who had almost full control of his flight. Although Yuri Gagarin spent just 1 hour 46 minutes in orbit he, along with Vostok 1, will forever be remembered for kickstarting the age of human space exploration.



4 Sputnik 1

This pioneering man-made object was the first to go into orbit around Earth

On 4 October 1957, the Soviet Union successfully sent the first ever artificial object into Earth orbit, using an R-7 rocket to get it there. The small, spherical satellite with four pronged legs was named Sputnik 1.

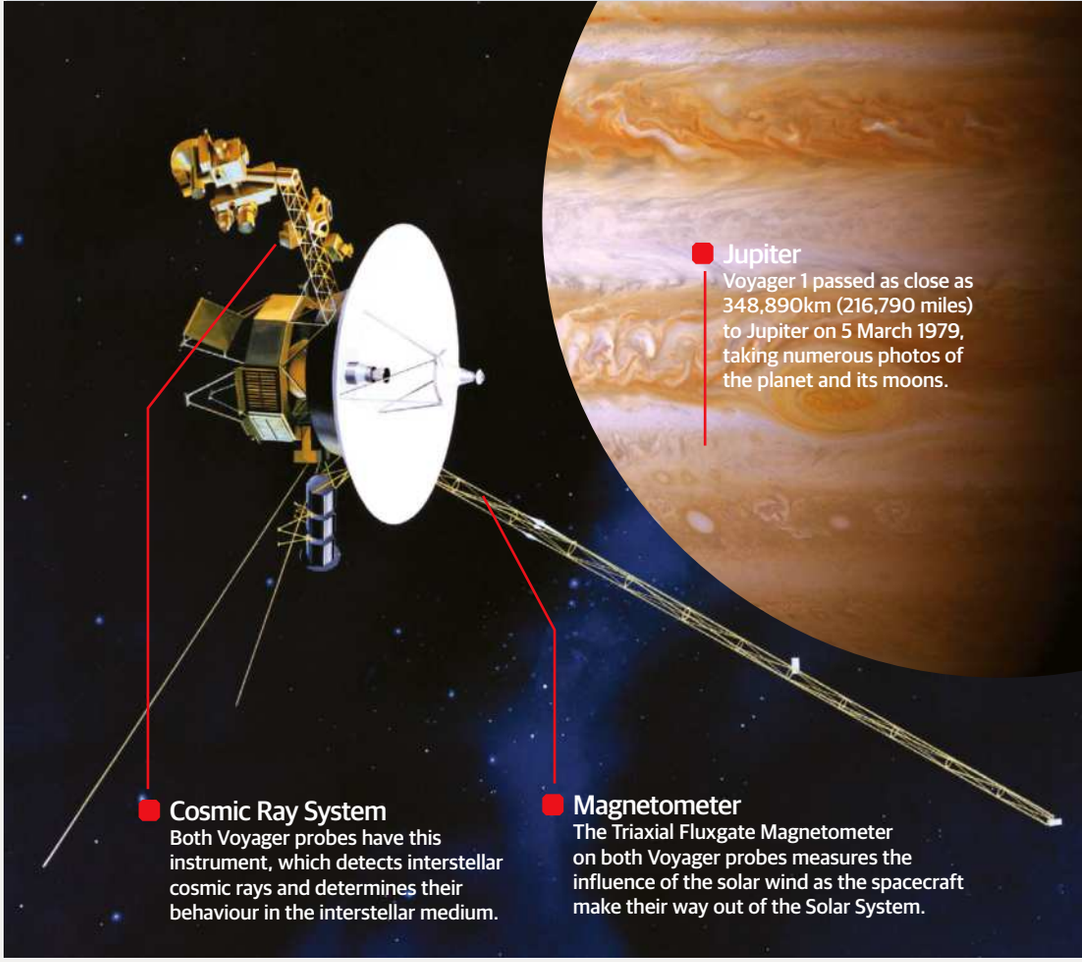
It was a major milestone not only for the Soviets but also for humanity as a whole, signifying that Earth orbit was both possible and feasible. Sputnik 1 led directly to the Space Race between the USA and USSR. However, it also gleaned some scientific data, such as measuring the electron density in the ionosphere. Upon reaching orbit, it entered an elliptical orbit, reaching over 900km (560 miles) from the surface of Earth. It transmitted radio signals for 22 days that were monitored around the world and eventually fell back into the atmosphere and burned up on 4 January 1958.

5 Voyager 1 & 2

Reaching the edge of the Solar System and beyond

The two unmanned Voyager spacecraft are the most intrepid of machines, and have escaped our Solar System into the realms of interstellar space.

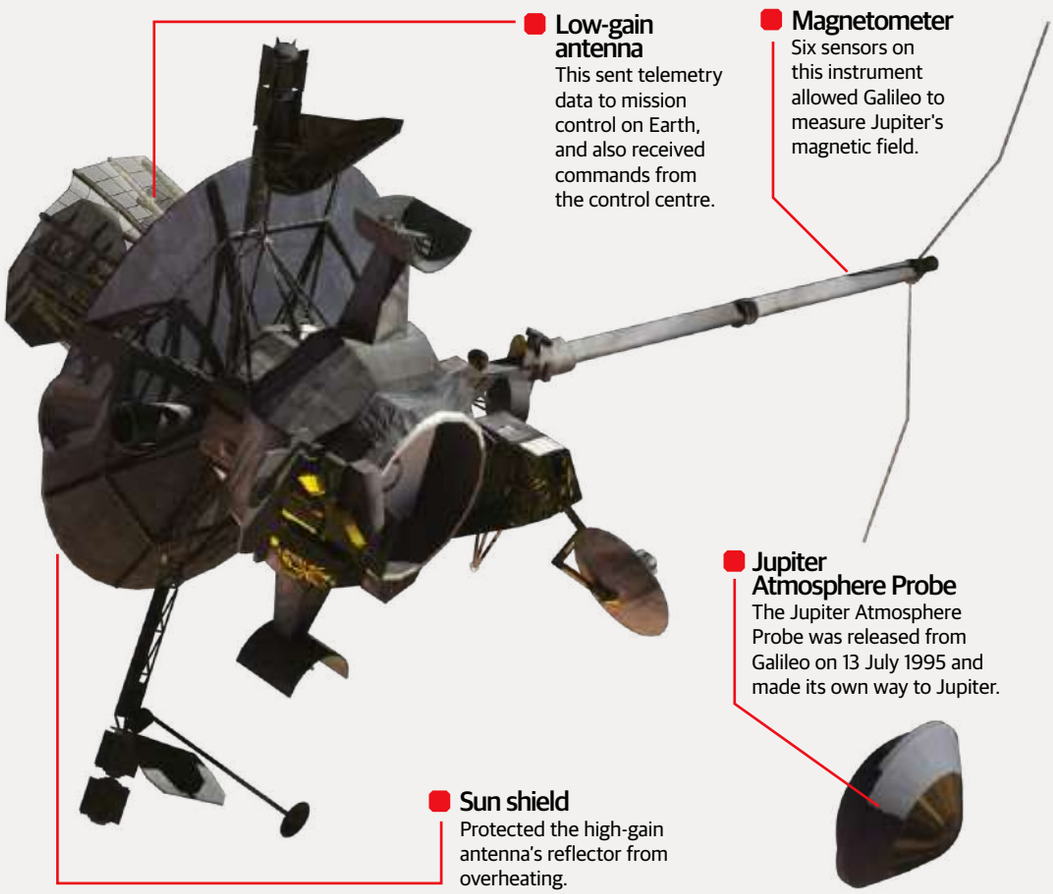
After achieving the primary mission to explore Jupiter and Saturn, they progressed to explore the outer planets, and studied the outer limits of the Sun's solar wind and magnetic field as part of the Voyager Interstellar Mission (VIM). They have enough power and fuel to operate into the 2020s. It was initially hoped that the Voyager spacecraft would reach the heliopause, and today both Voyager 1 and Voyager 2 have crossed into insterstellar space. Now, they'll drift through space, with Voyager 1, in about 40,000 years' time, passing within 15 trillion kilometres (9.3 trillion miles) of the star AC+79 3888. In 296,000 years, Voyager 2 will pass Sirius by 42.1 trillion kilometres (25 trillion miles).



Jupiter
Voyager 1 passed as close as 348,890km (216,790 miles) to Jupiter on 5 March 1979, taking numerous photos of the planet and its moons.

Cosmic Ray System
Both Voyager probes have this instrument, which detects interstellar cosmic rays and determines their behaviour in the interstellar medium.

Magnetometer
The Triaxial Fluxgate Magnetometer on both Voyager probes measures the influence of the solar wind as the spacecraft make their way out of the Solar System.



Low-gain antenna
This sent telemetry data to mission control on Earth, and also received commands from the control centre.

Magnetometer
Six sensors on this instrument allowed Galileo to measure Jupiter's magnetic field.

Jupiter Atmosphere Probe
The Jupiter Atmosphere Probe was released from Galileo on 13 July 1995 and made its own way to Jupiter.

Sun shield
Protected the high-gain antenna's reflector from overheating.

6 Galileo

The first craft to enter Jupiter's atmosphere

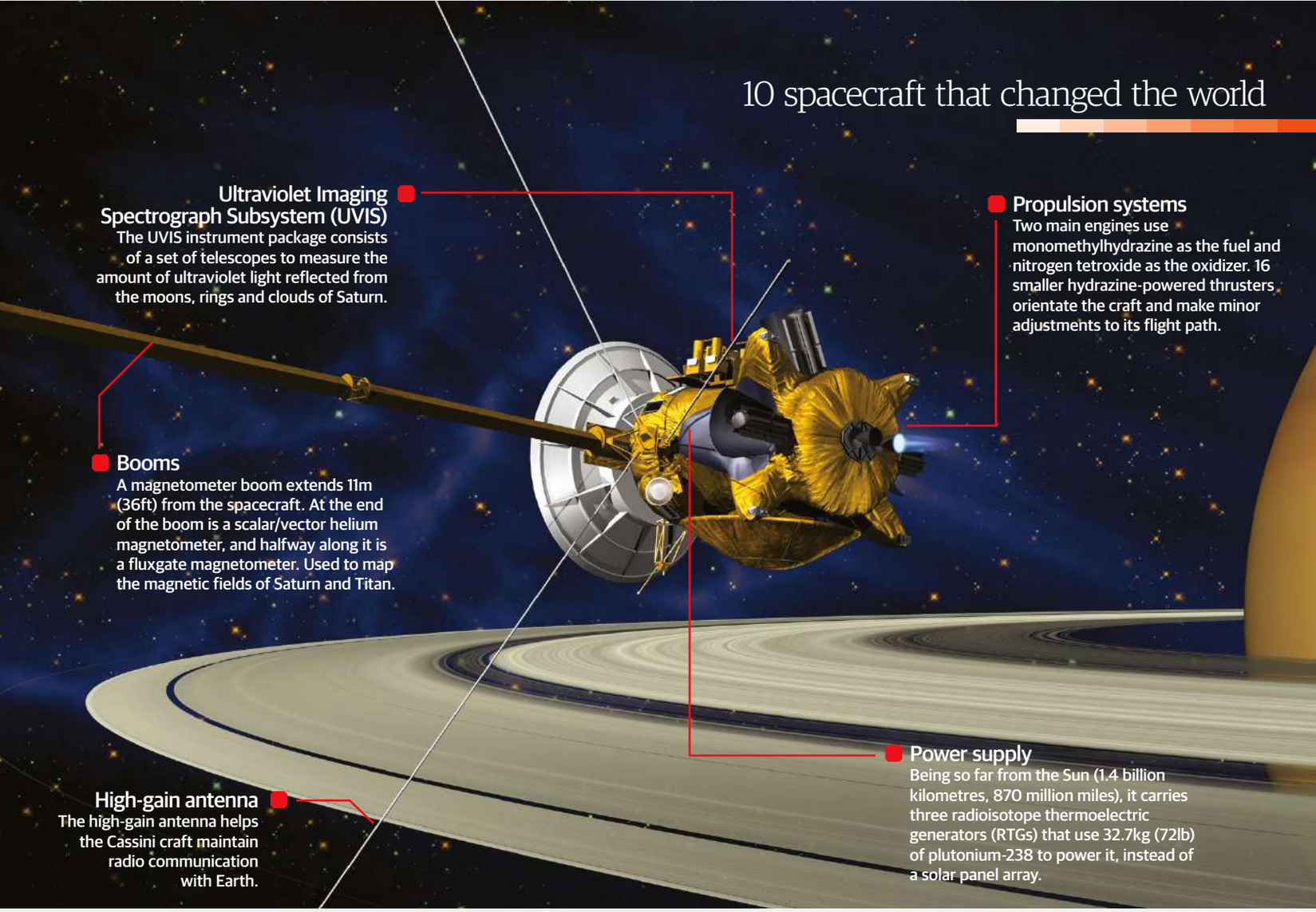
Galileo was taken into space inside the payload bay of Space Shuttle (STS-34) Atlantis on 18 October 1989. The craft consisted of a main orbiting vehicle and a Jupiter atmosphere probe. During its journey, it discovered extensive volcanism on the Moon and a huge impact basin on the Moon's far side. It passed within 1,600 kilometres (990 miles) of the Gaspra asteroid, and when passing the Ida asteroid at a distance of 2,400 kilometres (1,500 miles), Galileo's instruments discovered a small moon (Dactyl) orbiting it. Galileo released the Jupiter probe on 13 July 1995, and on 8 December 1995, it fired its main engine to become the first man-made object to orbit Jupiter. During the mission, Galileo made numerous surprising discoveries about the nature of Jupiter's atmosphere. These included finding a radiation belt 50,000 kilometres (31,000 miles) above its cloud layer, strong winds blowing at 600 kilometres per hour (400 miles per hour) and ten per cent less lightning activity than on Earth, though it can be up to a thousand times more powerful. After making 34 orbits of Jupiter, Galileo was nearly empty of fuel, so it was decided to crash the craft into Jupiter. After travelling a total of 4.6 billion kilometres (2.8 billion miles), Galileo disintegrated in Jupiter's dense atmosphere on 21 September 2003.

Spacecraft missions

And how they changed the world

Vostok Sputnik Apollo Saturn V Voyager
Galileo Cassini-Huygens Space Shuttle Soyuz Orion

4 October 1957	12 Apr 1961	14 Jun 1963	16 Jun 1963	23 Apr 1967	9 Nov 1967	21 Dec 1968
Sputnik 1 First man-made object reaches orbit	**Vostok 1** First human spaceflight	**Vostok 5** Longest ever solo Earth orbit flight	**Vostok 6** First woman in space	**Soyuz 1** First manned Soyuz flight, crashes on re-entry	**Apollo 4** First unmanned Saturn V flight	**Apollo 8** First manned Saturn V flight



7 Cassini-Huygens

The most complex interplanetary probe ever launched

At 6.7 metres (22 feet) tall and four metres (13 feet) wide, and with a weight of 5,712 kilograms (12,593 pounds), Cassini was the largest and most complex nmanned interplanetary spacecraft ever launched.

Its main objective was to use 12 on-board scientific instruments to conduct a four-year-long study of Saturn's atmosphere, surface details, the behaviour of its rings, magnetic environment and the composition of its moons, as well as to carry the Huygens lander spacecraft to Saturn's moon, Titan.

It began orbiting Saturn in 1 July 2004 and completed its prime objectives on 30 June 2008. Under the 'Cassini Solstice Mission'. Early in 2012, it studied the moons of Jarnsaxa and Mundilfari, and passed Enceladus. In the summer of 2012, passed Titan, Saturn's largest moon.

Cassini detected several new moons and revealed that Enceladus sprays out jets of ice crystals that feed into the rings of Saturn. On Saturn, lightning storms and hurricanes have been discovered, and on Titan they have found under its smoggy atmosphere, mountains, clouds, snow and liquid methane rivers and lakes, much like the conditions on Earth before life evolved here. To end the mission, Cassini was crashed into Saturn in 2017. It's signal was finally lost on 15 September.

"On Titan, they have found mountains, clouds, snow, and liquid methane rivers and lakes, much like the conditions on Earth before life evolved here"

On the surface of Titan

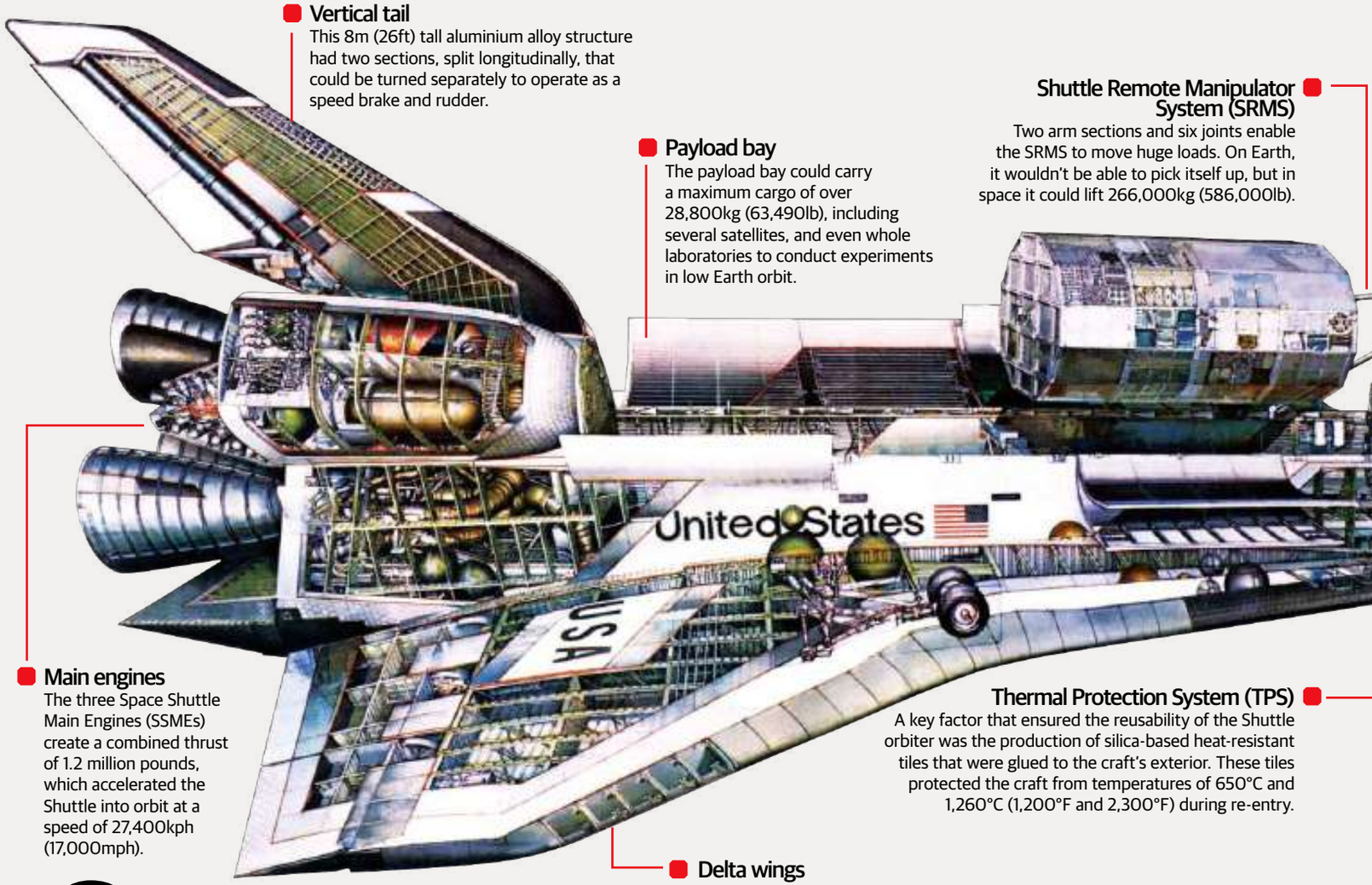
The Huygens lander was the first spacecraft to land on a body in the outer Solar System. Its mission was to carry six instruments to sample the chemical composition of Titan's atmosphere and to take photographs of its surface.

During its flight, the Huygens lander was checked every six months, and before being separated from Cassini its systems were checked and programmed to reactivate itself four hours before it entered Titan's atmosphere.

It landed at 10.2°S, 192.4°W and transmitted data for over three hours during its descent and from the surface before its batteries ran out.

Its photographs showed an orange surface littered with rocks and a ground mist composed of ethane or methane. The temperature of the surface was measured at -144°C (-291°F) and the wind speed was recorded at 241kph (150mph).

20 Jul 1969	14 Apr 1970	30 Jul 1971	11 Dec 1972	14 May 1973	27 Sep 1973	12 Aug 1977	20 Aug 1977	5 Sep 1977	12 Nov 1980
Apollo 11 First lunar landing	**Apollo 13** Mission aborted after oxygen tank exploded	**Apollo 15** First use of lunar rover	**Apollo 17** Last manned landing on the Moon	**Skylab** First American space station launched	**Soyuz 12** First flight of two-person Soyuz	**Enterprise** First manned Shuttle test flight	**Voyager 2** Voyager 2 launches	**Voyager 1** Voyager 1 launches	**Saturn** Voyager 1 flies by Saturn



Vertical tail
This 8m (26ft) tall aluminium alloy structure had two sections, split longitudinally, that could be turned separately to operate as a speed brake and rudder.

Payload bay
The payload bay could carry a maximum cargo of over 28,800kg (63,490lb), including several satellites, and even whole laboratories to conduct experiments in low Earth orbit.

Shuttle Remote Manipulator System (SRMS)
Two arm sections and six joints enable the SRMS to move huge loads. On Earth, it wouldn't be able to pick itself up, but in space it could lift 266,000kg (586,000lb).

Main engines
The three Space Shuttle Main Engines (SSMEs) create a combined thrust of 1.2 million pounds, which accelerated the Shuttle into orbit at a speed of 27,400kph (17,000mph).

Thermal Protection System (TPS)
A key factor that ensured the reusability of the Shuttle orbiter was the production of silica-based heat-resistant tiles that were glued to the craft's exterior. These tiles protected the craft from temperatures of 650°C and 1,260°C (1,200°F and 2,300°F) during re-entry.

Delta wings
The delta wings were constructed of a conventional aluminium alloy, and had a 'cranked delta' bend near the midpoint. This gave the Shuttle better aerodynamic lift than any other type of wing.

8 Space Shuttle

The world's first reusable manned spacecraft

Columbia was the very first Space Shuttle to blast off from the Kennedy Space Center on 12 April 1981. It was mounted on a huge 47m (154ft) long and 8m (27ft) diameter external tank, and two solid fuel booster rockets to take it into orbit. The boosters were jettisoned into the Atlantic Ocean where they were recovered and reused, and nine minutes after launch the external tank fell away into the atmosphere and burnt up over the Pacific Ocean. After its mission, the Shuttle 'orbiter' landed on a runway like a conventional aircraft. It could then be refurbished to be launched once more into space.

The flight of Columbia proved that the 2.5 million parts of the Space Transportation System (STS), as it was officially called, were fully functional. The Shuttle fleet consisted of Columbia, Challenger, Discovery, Endeavour and Atlantis. Atlantis flew the very last mission in July 2011. During this 30-year period, the combined fleet conducted 133 successful missions, made over 21,000 Earth orbits, travelled almost 873 million kilometres (543 million miles) and carried more than 850 astronauts.

Two major disasters struck the Shuttle programme. Challenger broke-up and exploded during lift-off on 28 January 1986, while Columbia disintegrated during re-entry on 1 February 2003.

Nonetheless, the Shuttle craft made many notable achievements, including 37 missions to the International Space Station. On 25 April 1990, Discovery deployed the Hubble Space Telescope, the world's first space-based optical telescope. In May 1992, Endeavour, built to replace Challenger, sent three astronauts to recover, repair and re-launch the INTELSAT VI communications satellite. From 1993 to 2009, the Shuttle programme made five trips to repair and service the Hubble Space Telescope, with Endeavour getting it functioning properly in December 1993.

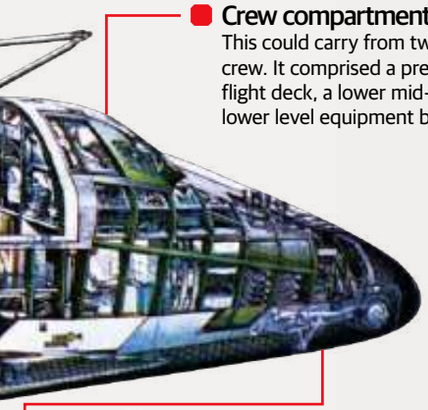
NASA's concept of the reusable Shuttle as a cost-effective vehicle that could make space travel safe and routine was ultimately never fulfilled. In the light of this, it was decided to cancel the programme after it had assembled the International Space Station, and focus on new space exploration projects.

Spacecraft missions

27 Nov 1980	12 Apr 1981	26 Aug 1981	24 Jan 1986	25 Aug 1989	18 Oct 1989	24 Apr 1990	7 Dec 1995	8 Dec 1995
Soyuz T-3 First flight of redesigned three-person Soyuz	**Columbia** First manned Shuttle orbital flight	**Saturn** Voyager 2 flies by Saturn	**Uranus** Voyager 2 has first-ever Uranus encounter	**Neptune** Voyager 2 becomes first spacecraft to observe Neptune	**Launch** Galileo spacecraft launches	**Discovery** Shuttle deploys Hubble Space Telescope	**Probe** Galileo space probe enters Jupiter's atmosphere	**Orbit** Galileo orbiter enters orbit around Jupiter



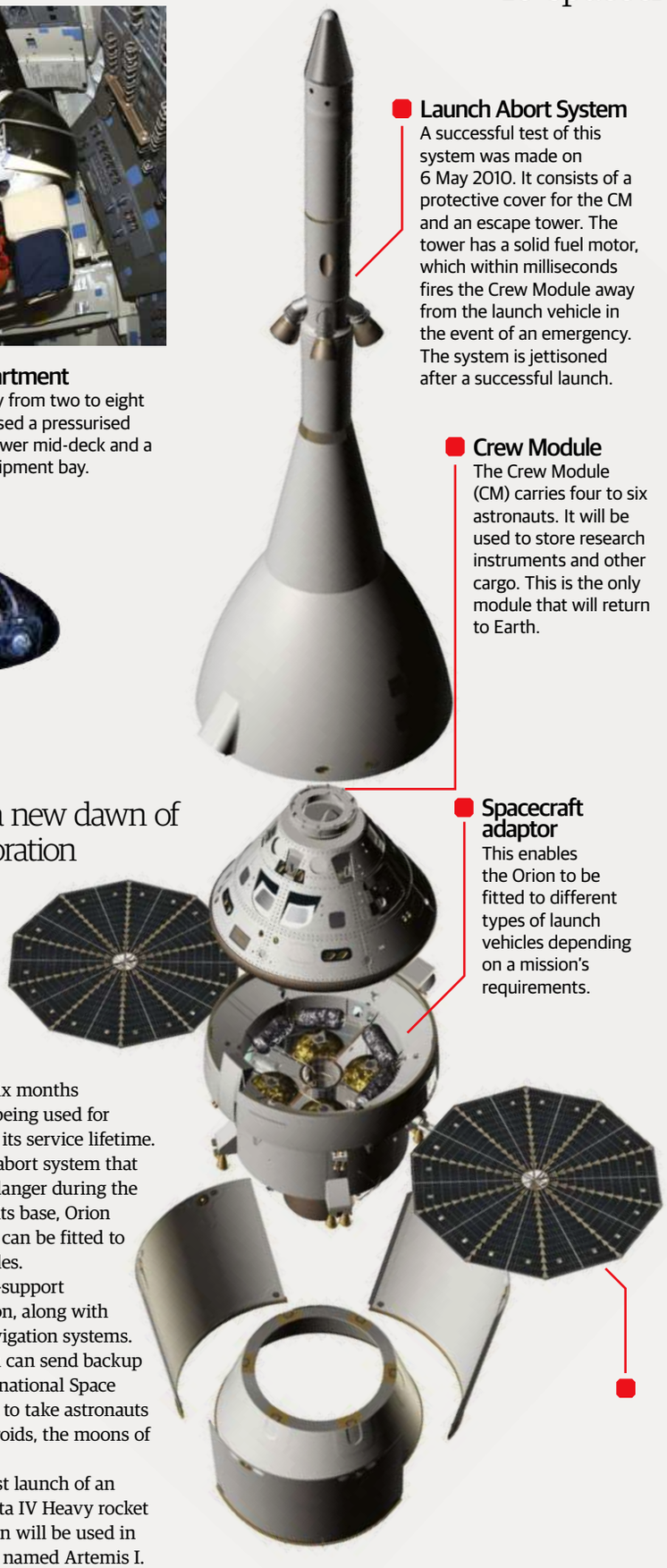
Crew compartment
This could carry from two to eight crew. It comprised a pressurised flight deck, a lower mid-deck and a lower level equipment bay.



Launch Abort System
A successful test of this system was made on 6 May 2010. It consists of a protective cover for the CM and an escape tower. The tower has a solid fuel motor, which within milliseconds fires the Crew Module away from the launch vehicle in the event of an emergency. The system is jettisoned after a successful launch.

Crew Module
The Crew Module (CM) carries four to six astronauts. It will be used to store research instruments and other cargo. This is the only module that will return to Earth.

Spacecraft adaptor
This enables the Orion to be fitted to different types of launch vehicles depending on a mission's requirements.



9 Orion

Heralding a new dawn of space exploration

Although still in development, the Orion spacecraft is already world-changing in terms of its advanced design and scale of ambition. Unlike other craft of its kind the Orion is being designed for long-term space missions lasting over six months which could see the vehicle being used for manned trips to Mars during its service lifetime.

It will use a revolutionary abort system that fires the capsule away from danger during the launch and lift-off stages. At its base, Orion has an adaptor unit so that it can be fitted to different rocket launch vehicles.

The craft has a unique life-support system and thermal protection, along with advanced propulsion and navigation systems.

When necessary, the Orion can send backup crews and cargos to the International Space Station, and can also be used to take astronauts to the Moon, near-Earth asteroids, the moons of Mars and Mars itself.

To test all its systems, a test launch of an unmanned Orion using a Delta IV Heavy rocket took place 2014. In 2021, Orion will be used in another uncrewed test flight, named Artemis I.



A Soyuz spacecraft orbiting the Earth with its solar array deployed

10 Soyuz

The longest-serving manned spacecraft

The Soyuz spacecraft was originally designed as an essential part of the mission to land Soviet astronauts on the Moon.

A modified (L1) two-man version of it was planned to be the equivalent of the Apollo Command Module, which would release a manned lander to the Moon.

On 23 April 1967, Soyuz 1 was launched to rendezvous and dock with another Soyuz craft in Earth orbit but it ended in failure. After this inauspicious start and the cancellation of the Moon programme, the Soyuz became a manned ferry to the Salyut space station in the Seventies.

Soyuz 19 docked with an Apollo spacecraft on 17 July 1975, marking the end of the Space Race between the USA and the Soviet Union.

The Soyuz T, with its improved electronics and navigation equipment, was introduced in June 1980 as the successor to the Soyuz 40, while the Soyuz TM replaced the Soyuz T in 1986 and serviced the Mir space station until its de-orbit in 2001. The latest version is the upgraded TMA that is used to service the International Space Station.

The basic craft carries three crew in a spherical orbital module, who are returned to Earth in a re-entry module that is positioned behind it. It can automatically dock to a spacecraft, though a manual override can be used when needed.

The Soyuz spacecraft has remained successful due to its modular design and ability to be modernised and modified to adapt to changing mission requirements.

15 Oct 1997 — Launch
Cassini-Huygens launches

17 Feb 1998 — Voyager 1
Voyager 1 becomes the most distant man-made object

31 Oct 2000 — Soyuz TM-31
First visit of Soyuz to ISS

21 Sep 2003 — De-orbit
Galileo orbiter intentionally crashes into Jupiter

1 Jul 2004 — Orbit
Cassini enters orbit around Saturn

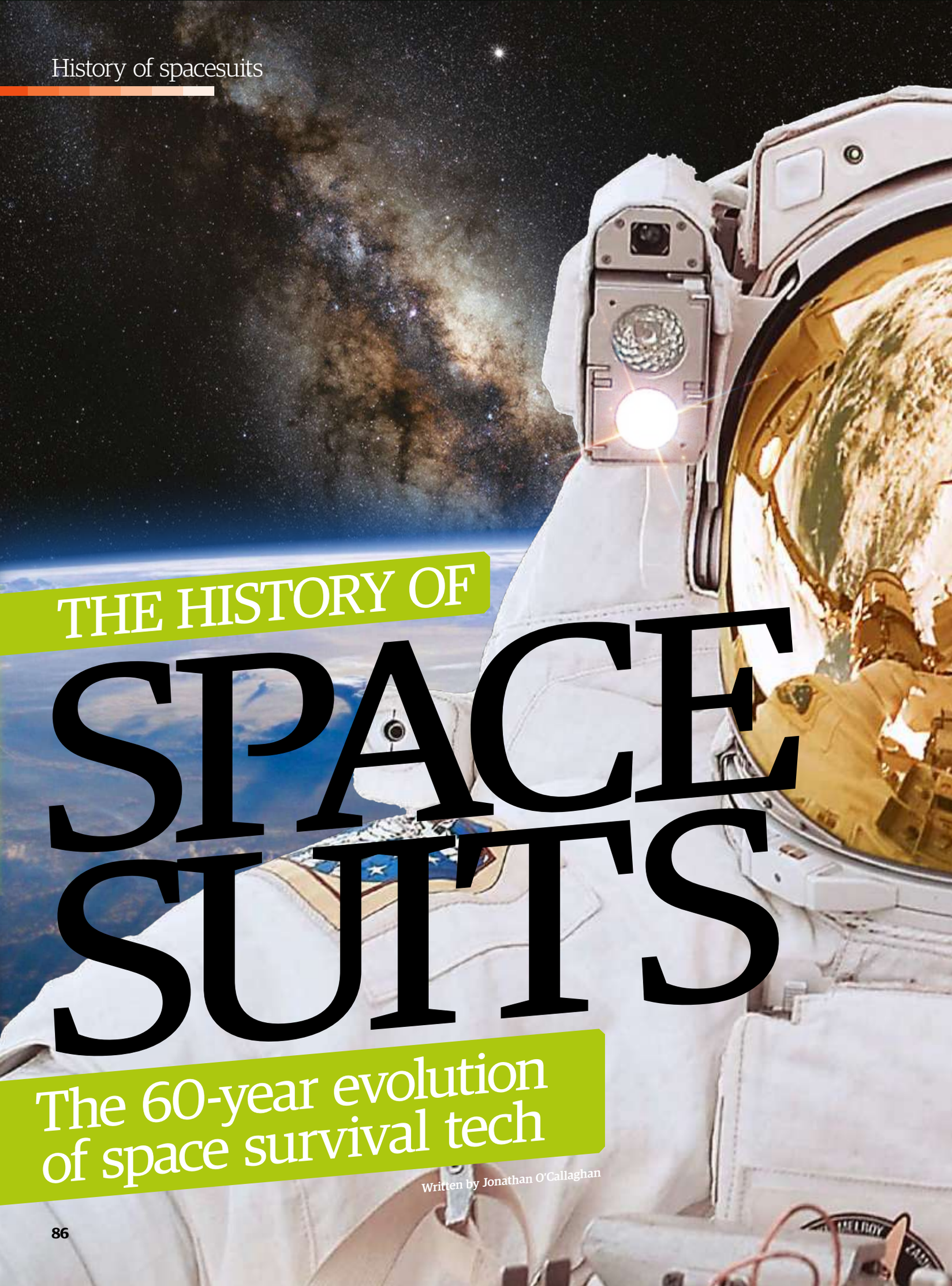
14 Jan 2005 — Huygens
The Huygens probe lands on Titan

8 Jul 2011 — Atlantis
Final flight of Space Shuttle programme

15 May 2012 — Soyuz TMA-04M
Soyuz takes a crew to the ISS

2014 — Launch
First unmanned test flight of Orion spacecraft

2021 — Artemis I
A final Orion test will take it to the moon.



THE HISTORY OF SPACE SUITS

The 60-year evolution of space survival tech

Written by Jonathan O'Callaghan



These miniature spacecraft have allowed us to operate in space for over half a century

When the United States and the USSR first decided to venture into the cosmos in the mid-20th Century, it was readily apparent that they would need something to protect their explorers from the harshness of space. While pressure suits had been used before on high-altitude jets, no one was quite sure how the human body would cope with weightlessness, and particularly with the vacuum of space, if a spacewalk was to be attempted.

One thing that was known for certain, however, was that exposure to space without a spacesuit would be fatal. At 20 kilometres (12 miles) above the Earth, the atmosphere becomes so thin and the atmospheric pressure is so low that the water and blood in a human body will boil. Above this point, which is known as the 'Armstrong limit', some sort of protection is vital. Therefore a mini-spacecraft designed to protect its occupant from the harshness of space, or a 'spacesuit' to us, was born.

Spacesuits come in a variety of shapes, sizes and uses. In the modern day on the International Space Station, astronauts wear flight suits for launch and re-entry that are largely designed to protect the occupant in case of a bailout. During a spacewalk, they have a much more sophisticated suit that allows them to operate in space.

While early iterations were bulky and basic, more modern spacesuits make use of computerised technology, cooling systems, movable joints and more to make operations in space more comfortable for astronauts. Future spacesuits, which are now in development, will allow greater dexterity and movement than ever before, letting astronauts operate on the surface of another body such as the Moon, an asteroid or Mars.

While modern astronauts can generally wear what they want on the ISS, in the early days of spaceflight there wasn't room to get changed into different clothes or spacesuits on a spacecraft. The Soviet Union's Vostok and Voskhod spacecraft, and the USA's Mercury and Gemini spacecraft, were all small and cramped, designed largely to test various aspects of spaceflight in orbit but not designed for long stays in space. The prospect of switching attire was not something that was tackled for some time; in fact, the first time a spacesuit was taken off during flight was not until December 1965 by astronaut Jim Lovell on the Gemini 7 mission.

The first spacesuit used in space was, of course, the one worn by Yuri Gagarin when he became the first human in space aboard Vostok 1 in April 1961. This was the Russian SK-1 suit, which was basically a glorified pressure suit designed only to protect Gagarin during the flight and if he had to bailout (which, ultimately, he did upon re-entry), and not for a spacewalk. The Russian SK-1 suit was used from 1961 to 1963 with its last wearer being Valentina Tereshkova, the first woman in space,

History of spacesuits





Yuri Gagarin became the first man in space in 1961

SUIT TYPE: SK-1
FIRST USE: VOSTOK 1 (1961)



© Mikhail Shcherbakov

Helmet
The helmet with a visor was attached to the suit, while an inflatable rubber collar could be used in the event of a water landing.

Weight
The SK-1 suit, which weighed 20kg (44lb), was used for the first six Vostok missions, including Yuri Gagarin's historic first trip into space.

Basic design
The SK-1 was designed only to protect the cosmonaut during launch, orbit and re-entry, and not for spacewalks.

YEARS
1970
1969
1968
1967
1966
1965
1964
1963
1962
1961
1960



Mercury suits were specially tailored to each astronaut

SUIT TYPE: Mercury
FIRST USE: FREEDOM 7 (1961)



Life vest
Weighing 10kg (22lb), the suit had an inflatable life vest attached from the third Mercury mission onwards.

Dexterity
The specialised gloves allowed astronauts to grasp controls, while a rigid middle finger allowed them to push buttons and switches.

Pressure suit
The suits had the ability to be pressurised in the event of a loss of capsule pressure, but this never occurred so was not needed.

YEARS
1970
1969
1968
1967
1966
1965
1964
1963
1962
1961
1960

on the Vostok 6 mission, albeit a slightly modified version for a female, known as the SK-2.

Hot on the heels of the Soviets in both spacecraft and spacesuits, the Americans had their own suit ready for the Mercury programme. This was a derivative of the Navy Mark IV suit that had been used for high-altitude flights. It used a 'closed loop' system to provide oxygen to the astronaut, had an aluminium-coated nylon exterior for thermal control, and straps and zippers for a snug fit. The spacesuit could also be pressurised in an emergency in the case of sudden spacecraft depressurisation, but this never happened throughout the Mercury programme.

The next spacesuit to arrive was arguably one of the most important ever designed. On the Voskhod 2 mission, the second and final flight of the short Soviet Voskhod programme, it had been decided that Alexey Leonov would attempt humanity's first spacewalk. The previous flight, Voskhod 1, had consisted of a three-man crew that were cramped into the Voskhod spacecraft. Somewhat dangerously, they flew without spacesuits as there wasn't space in the craft for all of the cosmonauts to wear one. Leonov, meanwhile, flew with just one other cosmonaut, and so was able to wear the Berkut spacesuit. This revolutionary suit, twice as heavy as the SK-1 suit worn by Gagarin, allowed Leonov to operate outside the spacecraft for 45 minutes, although he ultimately only stayed outside for 12 minutes. When Leonov tried to re-enter Voskhod 2, though, he found the suit had inflated too much and he had to bleed pressure from it to get back in the spacecraft. Following these complications, it was decided to retire the Berkut spacesuit.

Once again, just behind the Soviets were the Americans with their Gemini spacesuit. Like the Berkut suit, this was designed to allow astronauts to operate in the vacuum of space, or at least one iteration of it was. Four different Gemini suits were designed: the G2C as a prototype, the G3C



Alexey Leonov conducted the first ever spacewalk while wearing a Berkut spacesuit

SUIT TYPE:
Berkut
FIRST USE:
VOSKHOD 2 (1965)



Bulky
Movement within the Berkut suit was limited by its bulkiness, so it was used only once.

Life support
Various components, such as an oxygen supply, allowed Alexey Leonov to perform the first spacewalk in March 1965.

© Craigboy

YEARS
1970
1969
1968
1967
1966
1965
1964
1963
1962
1961
1960





The Gemini was a significant upgrade on the Mercury suit

SUIT TYPE:
Gemini
FIRST USE:
GEMINI III (1965)



Gemini G2C
There were three upgraded variants to the Gemini G2C suit pictured here: G3C, G4C and G5C.

Movement
The Gemini suit was a welcome upgrade to the rigid Mercury spacesuit, allowing astronauts to move more easily when pressurised.

Mylar
Edward White performed the first American spacewalk in an upgraded Gemini G4C suit, with additional layers of Mylar, on Gemini IV in 1965.

Nylon layers
The Gemini suits had six layers of nylon, an inner rubberised 'bladder', detachable gloves and full-pressure helmets.

YEARS
1970
1969
1968
1967
1966
1965
1964
1963
1962
1961

"Both the Americans and Soviets found those early spacewalks very difficult"

and G5C for launch and re-entry, and the G4C for spacewalking. Astronaut Ed White wore the G4C when he completed the first American spacewalk in June 1965. Using layers of nylon, removable boots and a full-pressure helmet, the Gemini suits were a vital stepping stone to the Apollo suits that would be used to walk on the Moon.

Both the Americans and Soviets, however, found those early spacewalks very difficult. They required huge amounts of exertion, and astronauts and cosmonauts would often get back into their spacecraft approaching exhaustion. As they were unable to get out of their spacesuit in their spacecraft, most of these early spacewalkers had to sit and wait until they returned to Earth to remove the uncomfortable apparel. It was actually Buzz Aldrin who solved the conundrum of spacewalks on the Gemini 12 mission in November 1966. He suggested training astronauts underwater for the rigours of space, and also consulted on the addition of handrails and footholds to the exterior of spacecraft to give spacewalkers something to hold on to in space, reducing the exertion they needed to perform even simple tasks. Without the important Gemini 12 mission, where Aldrin demonstrated effective operations in space, humans might not have been able to walk on the Moon.

Before Buzz Aldrin and Neil Armstrong walked on the lunar surface, however, the Soviets were developing their own spacesuit to be used on the Moon. First, they aimed to perfect the art of spacewalking with Yastreb. This spacesuit, with input on its design from Leonov, was a clear



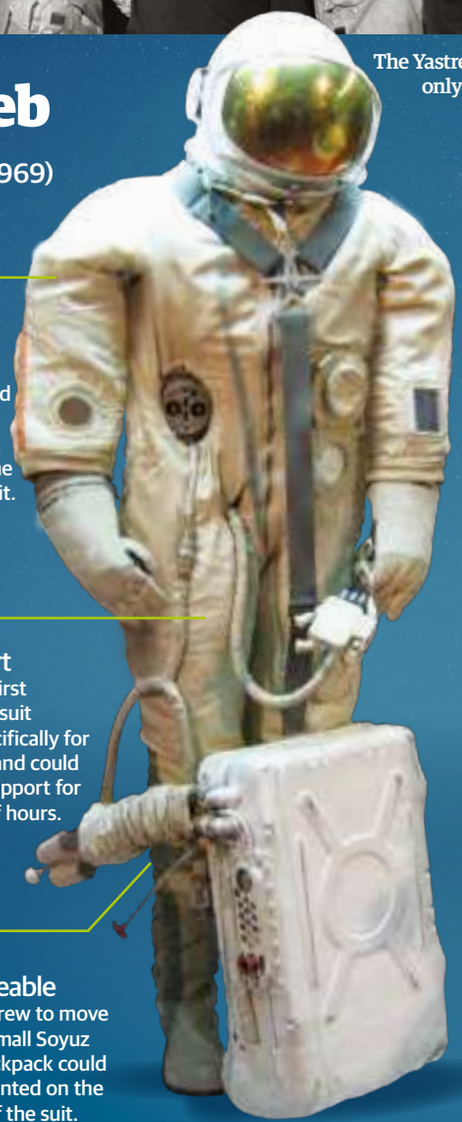
The Yastreb suit was only used once

SUIT TYPE: Yastreb
FIRST USE: SOYUZ 4/5 (1969)

Movement
This spacesuit used pulleys and lines to make it much easier to move in than the Berkut spacesuit.

Life support
This was the first Russian spacesuit designed specifically for a spacewalk, and could provide life support for two and a half hours.

Interchangeable
To allow the crew to move through the small Soyuz hatch, the backpack could either be mounted on the leg or chest of the suit.





SUIT TYPE: Krechet-94
FIRST USE: N/A

"Early spacesuits were bulky and difficult to manoeuvre"

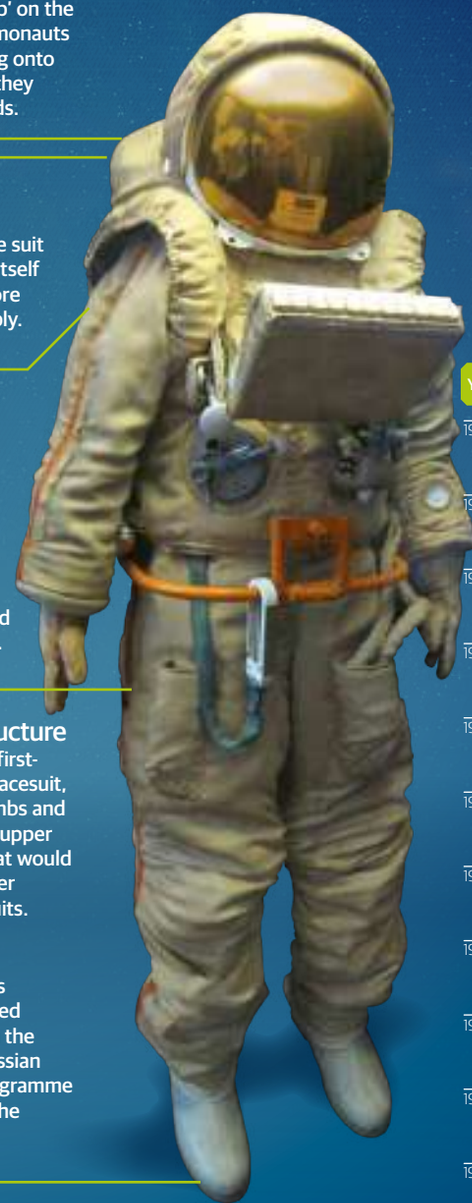
Self-righting
A metal 'hula hoop' on the back allowed cosmonauts to get up by rolling onto their side in case they fell over backwards.

Longevity
Weighing around 100kg (220lb), the suit could operate by itself for ten hours before requiring a resupply.

Suitport
This was the first-ever rear-entry suit, allowing cosmonauts to climb in through the back. This is a design feature being incorporated into modern suits.

Innovative structure
This was also the first-ever semi-rigid spacesuit, with soft fabric limbs and a hard aluminium upper torso, a design that would be adopted by later Russian and US suits.

Lunar walks
This spacesuit was designed to be used for spacewalks on the Moon, but the Russian manned lunar programme was cancelled in the early-Seventies.





upgrade over the previous Berkut suit; it used pulleys and lines to assist with movement, and was generally much more manoeuvrable. It was used only on a crew exchange between Soyuz 4 and 5 in 1969, with the other Soyuz missions not using pressure suits. Yastreb's successor was Krechet-94, another revolutionary Soviet suit intended for lunar spacewalks. Its major innovations were a rear-entry hatch, known as a suitport, and a semi-rigid design. Both of these concepts have been incorporated into modern spacesuits. When the Soviet lunar programme was cancelled, however, Krechet-94 was scrapped without a single flight under its belt.

NASA, meanwhile, had been hard at work on its own lunar suit. The Apollo A7L spacesuit was a huge step-up from the Mercury and Gemini spacesuits, providing additional levels of comfort, protection and manoeuvrability that were unmatched before. Designed by ILC Dover (see 'The story of the A7L' boxout on the next page), its primary purpose was ultimately to allow astronauts to operate effectively on the surface of the Moon. With 12 successful moonwalkers donning the suit, it was a resounding success. An A7L was tailor-made to each astronaut, but every Apollo mission actually required 15 suits, even though there was only a primary crew of three. This is because, of the primary crew, each astronaut had three suits: one for flight, one for training and one for backup. The remaining six suits for each mission came from the backup crew; each of them needed two suits, one for flight and one for training. For Apollo 11 through 17, therefore, 105 suits were made. An upgraded version of the spacesuit was also used for all three manned missions to the Skylab space station.

With their cancelled lunar programme behind them, the Soviets set about designing two new spacesuits, one for launch and re-entry and the other for spacewalking. Both these spacesuits

SUIT TYPE:
Apollo A7L
FIRST USE:
APOLLO 7 (1968)

Fishbowl helmet
The famous 'fishbowl' helmet was incorporated by NASA on the A7L to allow for an unrestricted view, and has been used on all of NASA's spacesuits since.

Life support
The entire A7L suit, including the backpack (which included over six hours of independent life support), weighed about 90kg (198lb).

On the Moon
The A7L (a prototype is pictured here) is most famously known as the one astronauts Neil Armstrong and Buzz Aldrin wore when they became the first humans on the Moon in July 1969.

Missions
The A7L was used for Apollo 7 to 14, while an upgraded version (the A7LB), which could last longer, was used on Apollo 15 to 17, the three Skylab missions and the Apollo-Soyuz Test Project mission.

Key features
This suit had rubberised joints for movement, five layers of nylon and rubber for protection, 'link-net' meshing to prevent joints ballooning and metal rings to connect the helmet and gloves.

YEARS
1975
1974
1973
1972
1971
1970
1969
1968
1967
1966
1965

The story of the A7L

The Apollo missions led to the creation of one of the most iconic spacesuits ever designed: the Apollo A7L spacesuit. The A7L was actually introduced by a fashion company called International Latex Corporation (ILC), who had been approached by NASA to design the suit alongside aerospace company Hamilton Standard. The latter, however, grew suspicious of ILC's competence and designed its own suit called Tiger, which was submitted to NASA for the Apollo missions. It was a flop, Hamilton Standard blamed ILC, and the fashion company lost its contract with NASA in 1962.

Several years later NASA ran a competition for a new suit. A dozen ILC employees took their original designs from their old offices. They finished the suit and submitted it to NASA and the A7L was born. Since then, ILC has made the modern EMU suit, and also designed NASA's next-gen Z-1 suit and even the airbags for NASA's Mars rovers Sojourner, Spirit and Opportunity that allowed them to land on the surface of Mars.


Buzz Aldrin on the Moon in the Apollo A7L

History of spacesuits





SUIT TYPE:
Sokol
FIRST USE:
SOYUZ 12 (1973)

The Sokol suit is not suitable for spacewalks

Protection
In the event of spacecraft depressurisation the Sokol suit is designed to offer protection for up to two hours.

Purpose
The Sokol suit is used during re-entry and landing only.

Layers
This suit has been upgraded over the years; the modern Sokol KV-2 has an inner layer of rubberised nylon and outer layer of white nylon canvas.

Boots and gloves
The boots are built in to the suit, while the gloves can be removed and reattached using specially designed wrist couplings.





SUIT TYPE:
Orlan
FIRST USE:
SALYUT 6 (1977)

Quick entry
The Orlan suit makes use of a rear-entry system through the backpack that allows astronauts and cosmonauts to don the suit in just five minutes.



In 2006, a retired Orlan suit called SuitSat-1 was released into orbit from the ISS

LCD screen
The main improvement of the modern Orlan-MK suit is that it has a mini-computer which processes data and alerts the wearer to malfunctions on a chest-mounted LCD screen.



would be so successful that they would become the cornerstone of the Soviet Union's, and later Russia's, space exploration. The Sokol spacesuit was a lightweight pressure suit that astronauts wore, and still wear, on the Soyuz spacecraft during launch and re-entry. These suits were the direct result of a tragedy when the three-man crew of Soyuz 11 were killed on 30 June 1971 as a result of their spacecraft depressurising on re-entry. They were unable to wear pressure suits as the spacecraft was too small, and therefore they were killed instantly. A redesign of the Soyuz spacecraft followed, with the number of crew reduced from three to two to allow them to wear suits during launch and re-entry. It would not be until 1980 that three people would travel in a Soyuz again, when the spacecraft was big enough to support three astronauts in pressure suits.

The Soviets' other suit was the Orlan, a versatile spacewalking suit that, although it has been upgraded over the years, is still in use today. In fact, the Chinese used it as the basis for the design of their Feitian suits that they use for their current spaceflights. It has a rear-entry port, allowing people to don it in minutes, and is semi-rigid (with a solid torso and flexible arms). It's used in the modern era for spacewalks on the ISS, having previously been used both on the Salyut and Mir space stations. The only other spacesuit designed by the Russians was the Strizh suit, which was developed to be used on the Russian Buran space shuttle. Like their earlier lunar programme this was scrapped, although the suit was lucky enough to have one flight on a mannequin during an unmanned test flight of the shuttle in 1988.

The Americans also settled on a preferred series of spacesuits. In the early-Eighties, the Extravehicular Mobility Unit (EMU) was introduced, originally to be used on spacewalks outside the Space Shuttle and is now used on the ISS. In



Bruce McCandless II performed the first of three flights of NASA's Manned Maneuvering Unit (MMU) in 1984

© NASA



This blue suit was used from STS-5 in 1982 until 1986's Challenger tragedy

"Buzz Aldrin solved the conundrum of spacewalks on the Gemini 12 mission"

SUIT TYPE:
EMU
FIRST USE:
STS-6 (1983)



Comfort
The EMU must be put on in parts. Under the external suit are Urine Collection Devices (UCDs) and Liquid Cooling and Ventilation Garments (LCVGs).

Identity
The red stripes on the suits helps ground control differentiate between the astronauts when they are out on spacewalks.

Shuttle EVAs
This is the spacesuit that NASA used for spacewalks on the Space Shuttle, and it is now being used in tandem with the Orlan suit on the ISS.



SUIT TYPE:
Shuttle Ejection Escape Suit
FIRST USE:
STS-1 (1981)



Four missions
This suit was used only for the first four NASA Space Shuttle missions, before being replaced by LES and ACES.

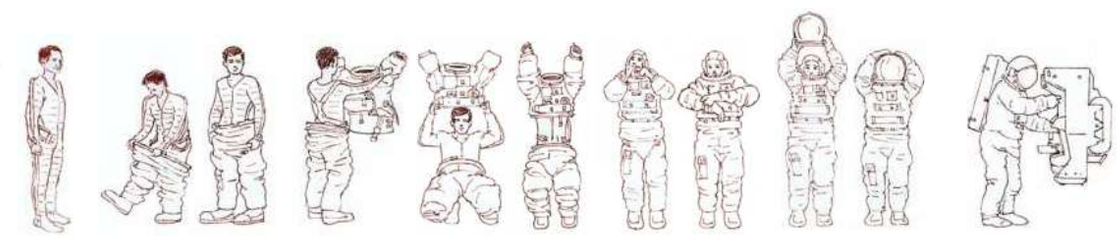
Ejection
The Shuttle Ejection Escape Suit was designed to protect astronauts in the event of ejection, until ejector seats were removed from the Shuttles after STS-4.

Survival
This suit could allow crewmembers to survive an ejection up to 24.4km (15.2 miles) high at a speed of up to Mach 2.7.



Getting ready for space

You can't just don a multimillion-dollar EMU spacesuit and immediately jump out into space. Astronauts must undergo a lengthy process for several hours to get their body prepared to enter the pressurised suit and then operate in the vacuum of space. So, what do they have to do to get themselves ready?



1. Reduce pressure in the airlock and pre-breathe 100 per cent oxygen for four hours.
2. Pull on the suit's lower torso.
3. Attach components to spacesuit.
4. Pull on the suit's upper torso.
5. Insert food bar and water source into suit.
6. Attach the helmet to the upper torso and attach tubes to suit.
7. Check for leaks, then exit airlock.

History of spacesuits

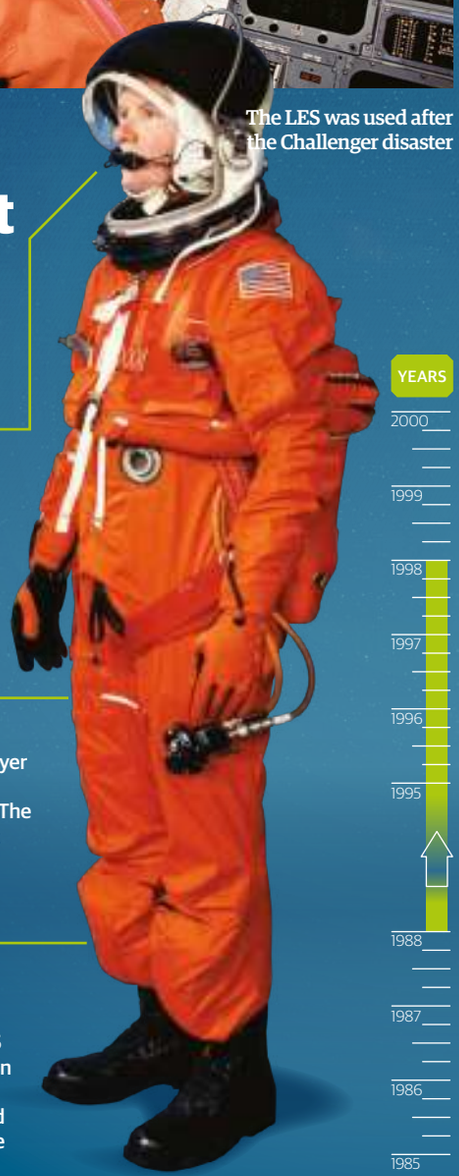


The LES was used after the Challenger disaster



The crew of the STS-121 mission to the ISS

SUIT TYPE:
Launch Entry Suit (LES)
FIRST USE:
STS-26 (1988)



Communications
An additional new communications cap allowed the Space Shuttle crews to talk to ground control during launch and re-entry.

Nomex layer
LES had a Nomex outer layer and was entered by crew using a rear-entry zipper. The helmet design also meant astronauts had to wear a communications cap.

Visibility
Owing to their colour, LES and ACES were also known as 'pumpkin suits'. The orange colouration helped the suit be spotted in case of an ejection into water.

YEARS
2000
1999
1998
1997
1996
1995
1988
1987
1986
1985

SUIT TYPE:
ACES
FIRST USE:
STS-64 (1994)



Upgraded suit
The main difference between LES and ACES was that the latter was fully pressurised, while the former was only partially pressurised.

Replacement
ACES was in use from the 64th Space Shuttle mission (STS-64) to the final one, STS-135, replacing the very similar Launch Entry Suit (LES).

Key features
The one-piece suit had a ventilation system, full-pressure helmet, detachable gloves, boots and survival kit (including light sticks and a life raft).

YEARS
2015
2014
2013
2012
2011
1994
1993
1992
1991
1990

tandem with this was the Shuttle Ejection Escape Suit that, as you might have guessed, was used on the Space Shuttle as a launch and re-entry suit. It was scrapped after the fourth Space Shuttle missions in favour of regular flight suits, while the Challenger disaster in January 1986 prompted the design of the iconic orange Launch Entry Suit (LES), and later the Advanced Crew Escape Suit (ACES), which were used for the remaining Space Shuttle missions until it was retired in July 2011.

Despite the relative advances in spacesuit technology, though, operating in space is still no easy feat. It's slow going, and even installing a simple component on the exterior of the International Space Station can take several hours. To assist astronauts and cosmonauts, the gloves of a spacesuit often have rubberised fingertips that help with grip, while loops allow tools to be tethered to the gloves. Equipment can also be stored on the torso of a modern spacesuit, while a number of dials and switches on the front of the suit allow astronauts to regulate their temperature, pressure and more.

These complex machines have been vital in allowing astronauts to operate effectively and safely in space for over 60 years. While early space missions involved limited stays of just minutes in space, modern-day astronauts rely on their spacesuits for hours at a time as they work on the exterior of the International Space Station, and without spacesuits, extravehicular activities (EVAs), or spacewalks, would simply not be possible. And of course, without the complex suits designed for the Apollo missions, astronauts would also not have been able to walk on the Moon. Spacesuits have allowed us to study and explore space like never before, and their continued evolution and development will allow us to ultimately set foot elsewhere in the Solar System in decades to come.

"Without spacesuits EVAs, or spacewalks, would simply not be possible"

SUIT TYPE:
Z-1
FIRST USE: TBC

Built for a new generation
The Z-1 is NASA's developmental spacesuit that will be used for missions in the future. These could include spacewalks on the Moon, an asteroid and Mars.

YEARS
2022
2021
2020
2019
2018
2017
2016
2015
2014

Unrivalled flexibility
The Z-1 is designed to be incredibly manoeuvrable, allowing astronauts to easily bend down to pick up rock samples or operate machinery.

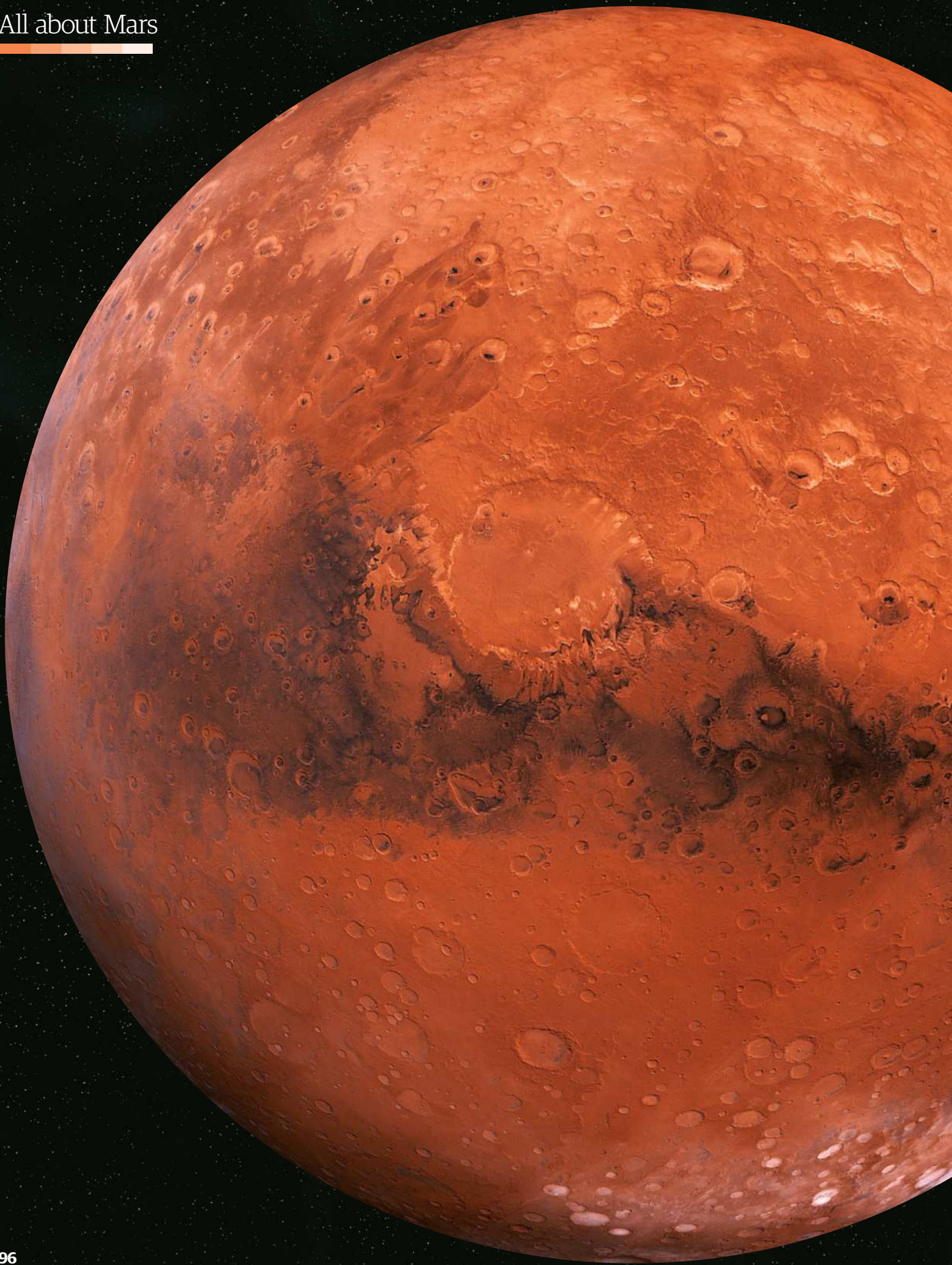
Walking on Mars
The Z-1, which can be left outside a spacecraft for astronauts to climb into, will be used both for walks in the zero-gravity of space and on the surface of another world.

Innovative suitport
One major innovation is that, like Russia's Orlan spacesuit, astronauts will be able to enter the Z-1 through a rear-entry hatch.

Joint evolution
The added manoeuvrability of the suit comes from the joints, such as the arms and knees, which contain bearings to greatly increase the degree of movement.



Astronaut Randy Bresnik carries out pressure tests on the Z-1 spacesuit





All about... MARS

Written by Shanna Freeman

The fourth planet from the Sun, the red and varied landscape of this once Earth-like planet has fascinated humanity since we first viewed it in the night sky. Discover just why this planet holds such allure, and why we're so keen to uncover its secrets

Because it appears red due to the rust in its atmosphere, Mars has long been called The Red Planet. Its 'bloody' appearance is also why it was named after the Roman god of war. But that potentially scary appearance hasn't kept us from wanting to learn more about it. Mars formed about 4.6 billion years ago, along with the other planets in the Solar System. After the initial formation, Mars was bombarded at length by meteors, which caused its heavily cratered appearance. As the planet separated into layers, molten rock in the mantle pushed through the crust, resulting in volcanic activity. The activity released a lot of heat from the core, which led it to cool down very quickly. Atmospheric water likely froze, causing flooding, but the lack of atmospheric pressure meant that water was swirled away by solar winds. Eventually, Mars settled down into the dry, dusty planet we've been watching since ancient times.

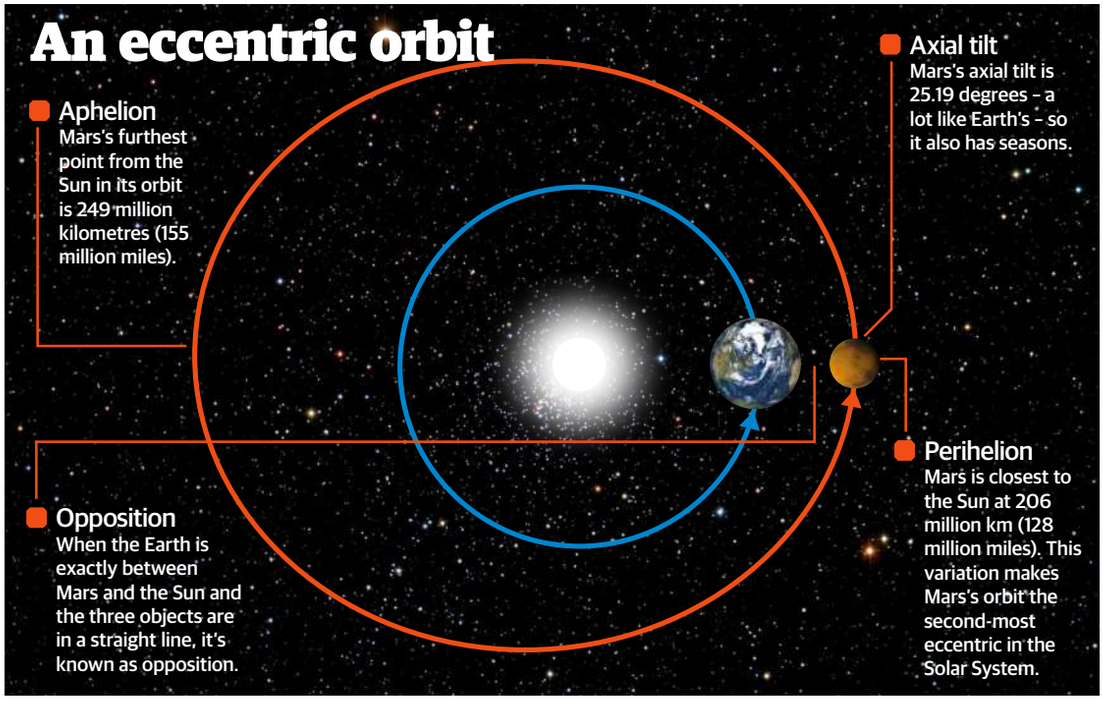
We can easily see Mars from Earth without a telescope, and it's actually easier to see when it's further away from the Earth in its orbit because our atmosphere gets in the way. We've sent lots of probes to the planet, including NASA's recent Perseverance rover. So far we've discovered that Mars is so much like the Earth, but also so very different. It is a terrestrial planet and has almost identical geographical features and a similar axial tilt (which results in seasons). It also has basically no atmosphere, no liquid water and wildly fluctuating temperatures on the surface. If there are any Martians lurking around, they have to be a hardy group - and so far they've eluded detection. Mars is red, but not all red. Although we can see the planet, we can't actually see any of its features. We do, however, see albedo features, areas of light and dark. While most of the planet is red there are also bright white areas at the poles, some upland areas, and also in the form of ice clouds. The darker spots are places where the intense wind has removed the ruddy dust to expose basaltic volcanic rock.

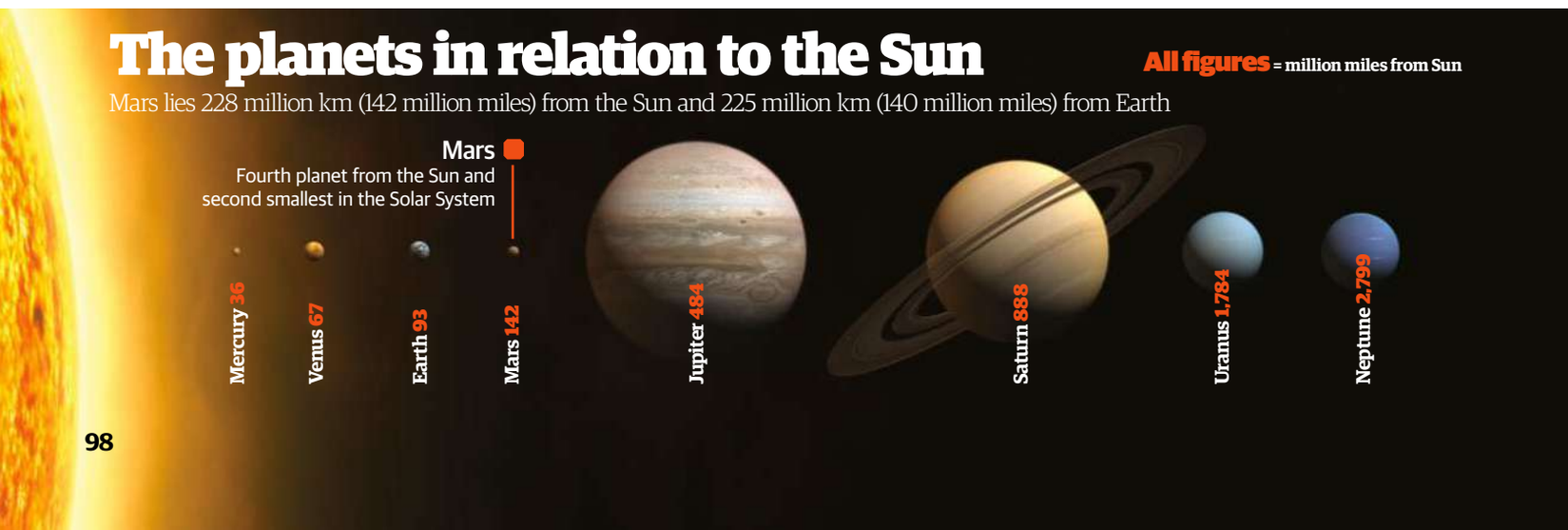
Mars is the fourth planet from the Sun in the Solar System, right between the Earth and Jupiter. Size-wise it is the second-smallest planet, behind Mercury. Despite all of the Earth comparisons, it's about half the diameter of Earth, and much less dense. In fact, its mass is about 11 per cent that of Earth's and its volume is about 15 per cent. But because there are no oceans on Mars, the smaller planet has the same amount of dry land as the Earth does.

The planet's average distance from the Sun is about 228 million kilometres (142 million miles). It takes 687 Earth days to orbit the Sun, but Mars has a very eccentric elliptical orbit. Its eccentricity is 0.09, which is the second-most eccentric in the Solar System behind Mercury (the Earth has an orbital eccentricity of 0.0167, which is almost a circle). But we believe that Mars once had a much rounder orbit - it has changed due to gravitational influences from the Sun and other planets. Rotation-wise, a Martian day is just a bit longer than an Earth day at 24 hours, 39 minutes and 35 seconds. Mars is also tilted 25.19 degrees, close to the Earth's axial tilt of 23.44 degrees. That means depending on where the planet is in its orbit around the Sun, different hemispheres will be exposed to more light - better known as seasons. They aren't seasons like we know them, which are fairly equal in length on most parts of the surface of Earth. On Mars, spring is seven months long, for example, while winter is only four. The seasons are longer because the year is longer - Mars is further away from the Sun than the Earth - but they vary because of the eccentricity of Mars' orbit.

Mars also has two natural satellites, or moons - Phobos and Deimos. Both are potato-shaped and may have been asteroids that got trapped by Mars' gravitational pull or they could have

"Because there are no oceans on Mars, it has the same amount of dry land as the Earth does"





formed from material ejected from Mars during impact. The planet might also have other tiny satellites that have yet to be discovered.

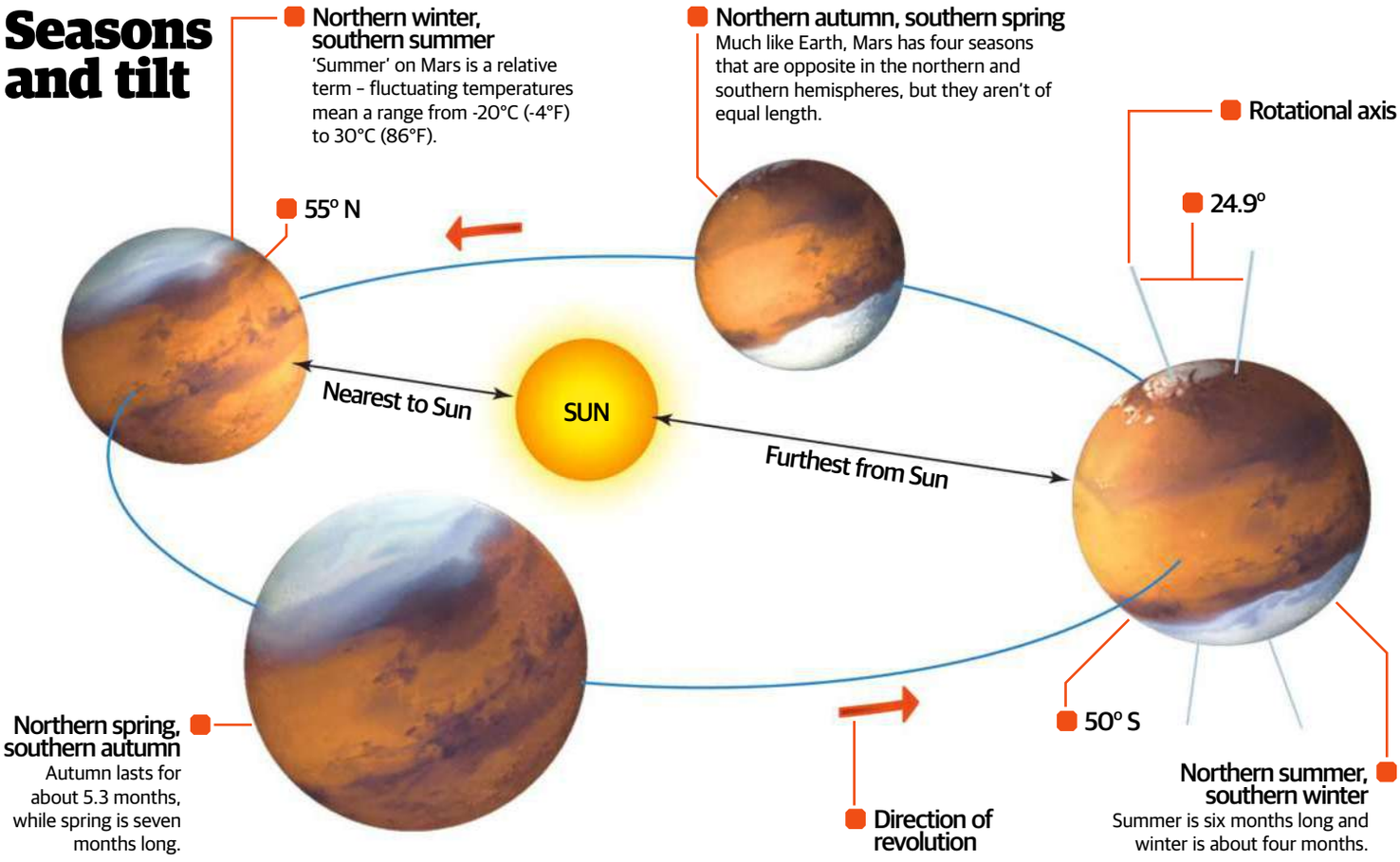
Over the years, science fiction has often portrayed Mars as a sister planet to Earth and although there are many key differences – the small matter of life, for example – a true understanding can often be reached by making the right comparisons. NASA has referred to Earth as 'one of the best comparative laboratories' and the study of Mars can provide scientists with a control set for studying the potential for life beyond our world.

As mentioned, the chief of these differences is the size of the planet: Mars is a smaller world with 53 per cent the diameter and just 11 per cent the mass of Earth. The surface gravity on the Red Planet is 38 per cent that of Earth's, meaning that a human who can jump one metre (3.3 feet) on Earth could jump 2.6 metres (about nine feet) on Mars. As well as the similar land surface area the atmospheric chemistry is relatively similar especially when Earth and Mars are compared to other planets in the Solar System. Both planets have large polar ice caps made primarily of water ice, according to current thinking. Other similarities include a similar tilt in their rotational axis, which causes strong seasonal variability on the planets' surfaces.



Mars is around half the size of Earth and has just 11 per cent of its mass

Seasons and tilt

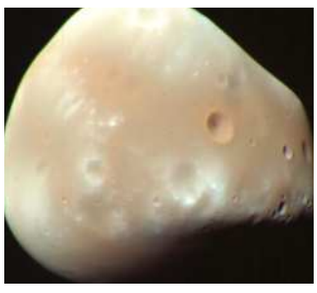


The moons of Mars



Phobos

Phobos is the bigger of Mars's two satellites, and orbits the closest. In fact, it orbits closer to its planet than any other satellite in the Solar System. The distance from the moon to the planet is about 6,000km (3,700 miles) from the surface. Phobos has a radius of about 11km (seven miles) and is irregularly shaped and non-spherical. Its biggest feature is a large impact crater named Stickney, which has a diameter of about 9km (5.6 miles).



Deimos

Deimos is much farther from Mars than Phobos at around 23,400km (14,600 miles) away. It's also significantly smaller, with a radius of around 6km (four miles), and takes much longer to orbit Mars at 30.4 hours. Deimos, like Phobos, is not at all spherical. It has a very porous surface, and also features large craters relative to its size, with the two largest being Swift and Voltaire. Both craters are believed to be between 1km and 3km (0.6 and 1.9 miles) in diameter.

Mars inside and out

Its make-up may resemble Earth's, but Mars is a very different planet

Mars is a terrestrial, or rocky, planet – just like Earth. It also has a differentiated internal structure, meaning that there's an outer crust, a mantle and a core. However, that structure isn't exactly like the Earth's.

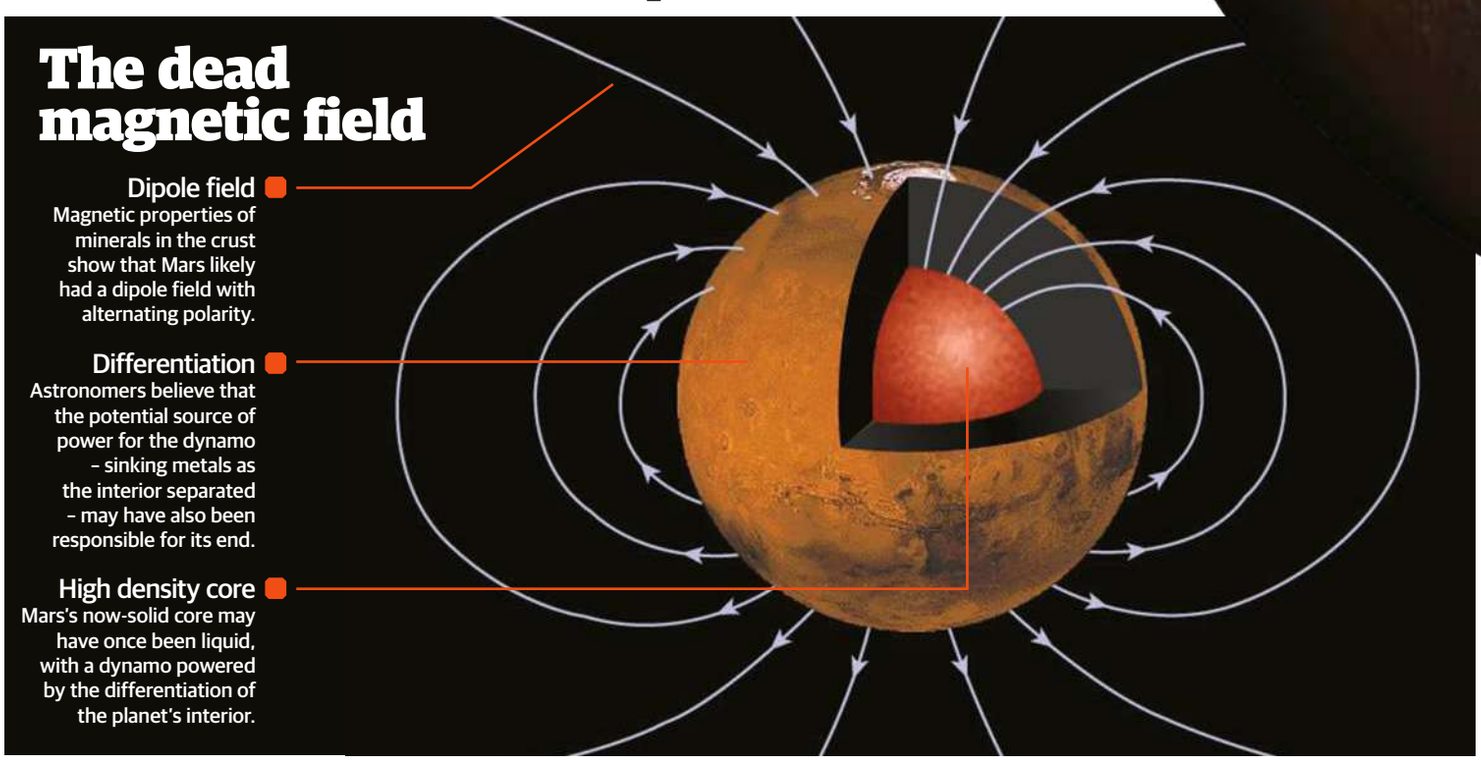
At the centre of the planet, Mars's core is believed to be between around 3,000 and 4,000 kilometres (1,850 and 2,500 miles) in diameter. It's mostly made up of iron, with nickel and traces of other elements, such as sulphur. Scientists believe that the core is mostly solid but may also contain a fluid layer. There is no magnetic field generated at the core, but Mars may have had a magnetic field in the past. There are currently areas of magnetisation at different places on the planet's surface. The differentiation process, in which heavier metals such as iron sunk through to the core while Mars was forming, may be responsible for the end of its magnetic field.

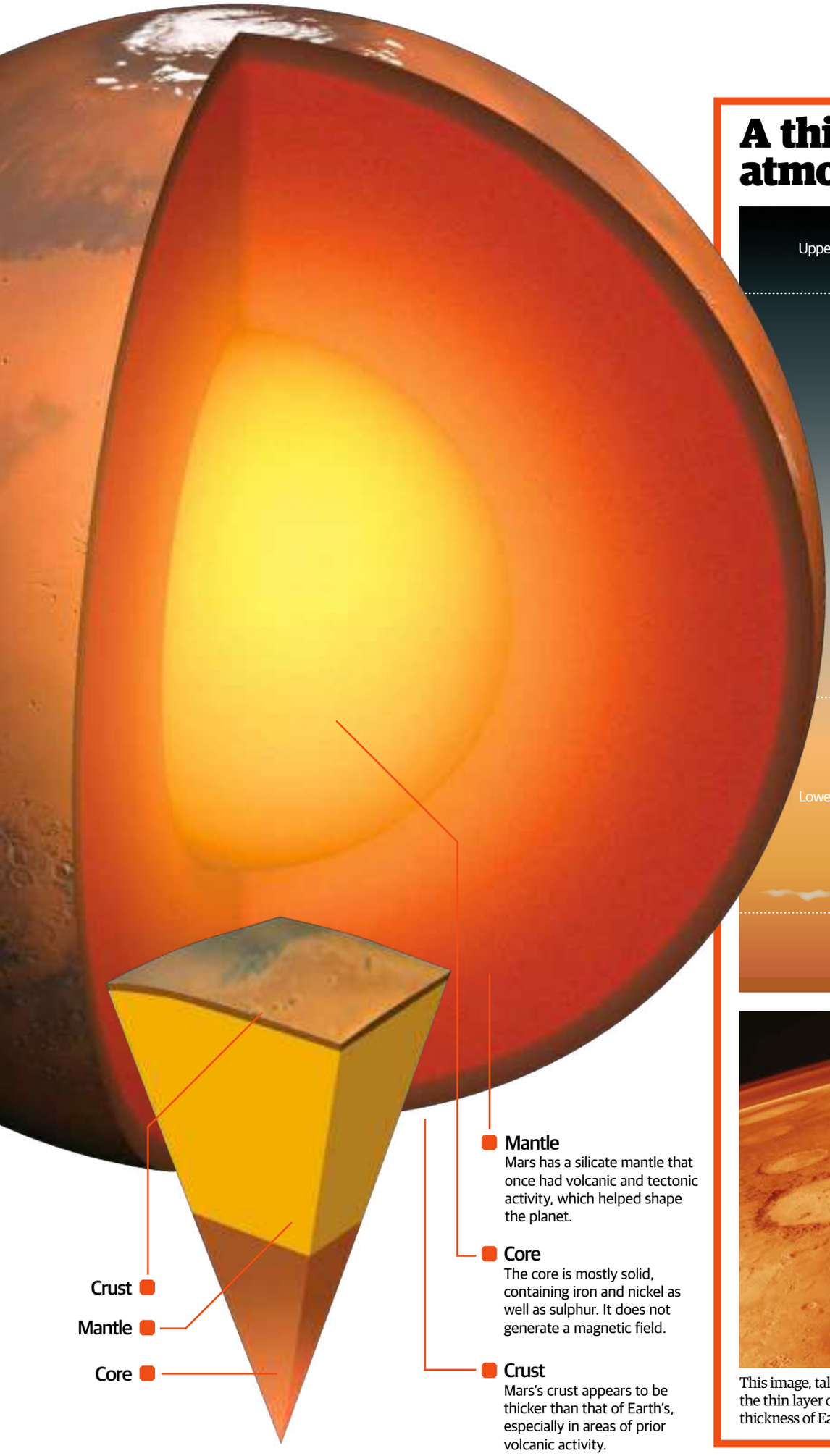
Atop the core lies Mars's silicate mantle, which is between 1,300 and 1,800 kilometres (800 and 1,100 miles) thick. Volcanic activity on the planet's surface originated here, resulting in the huge volcanoes, lava flows and other features that can be found on Mars's surface – however, the most recent volcanic activity likely took place about 2 million years ago. That may not be particularly recent by our standards, but it's fairly recent when it comes to Mars's history. These were lava flows, however; the volcanoes appear to be extinct.

Finally, there's the crust, which is about 25 to 80 kilometres (16 to 50 miles) thick. It contains oxygen, silicon, iron, calcium and other metals. The high concentrations of iron and oxygen result in rust – iron oxide – which is responsible in part for the red appearance of Mars. At its thickest, the crust is more than twice as thick as the Earth's crust. The surface is covered with regolith in many places – a loose conglomerate of broken rocks, dirt and dust that sits lightly on the surface.

There isn't much atmosphere – the solar wind strips away molecules and carries them out into space. What little atmosphere is left is made up of about 95 per cent carbon dioxide, three per cent nitrogen, two per cent argon with trace gases as well.

"The solar wind strips away molecules and carries them out into space"



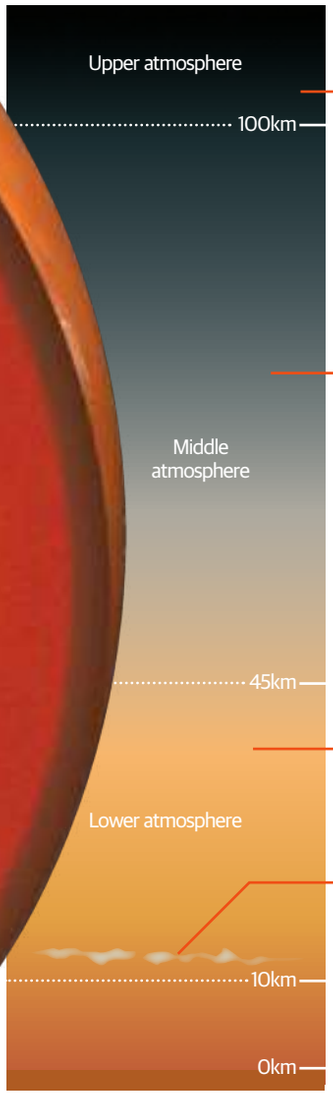


Mantle
Mars has a silicate mantle that once had volcanic and tectonic activity, which helped shape the planet.

Core
The core is mostly solid, containing iron and nickel as well as sulphur. It does not generate a magnetic field.

Crust
Mars's crust appears to be thicker than that of Earth's, especially in areas of prior volcanic activity.

A thin atmosphere

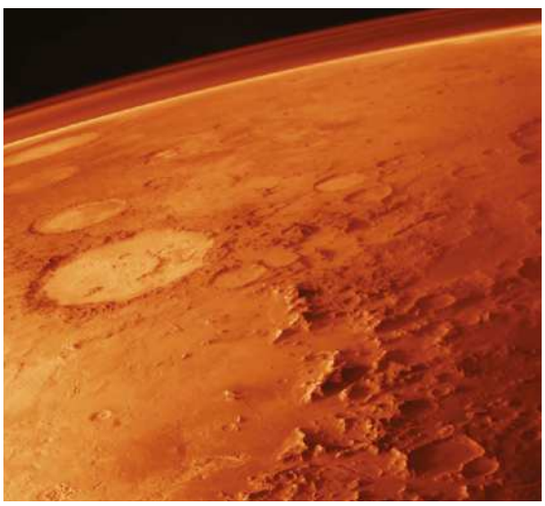


Upper atmosphere
Also known as the thermosphere, this layer is heated by the Sun. The lack of a magnetic field means that the gases separate out into space.

Middle atmosphere
In the middle atmosphere, the Martian jet stream swirls the surface dust and gives the sky its orange colour.

Lower atmosphere
The atmosphere contains 95 per cent carbon dioxide, three per cent nitrogen, two per cent argon and traces of elements such as methane.

Thin ice clouds
Strong winds sweeping off Mars's polar ice caps, along with atmospheric sublimation of carbon dioxide, help create these thin ice clouds.



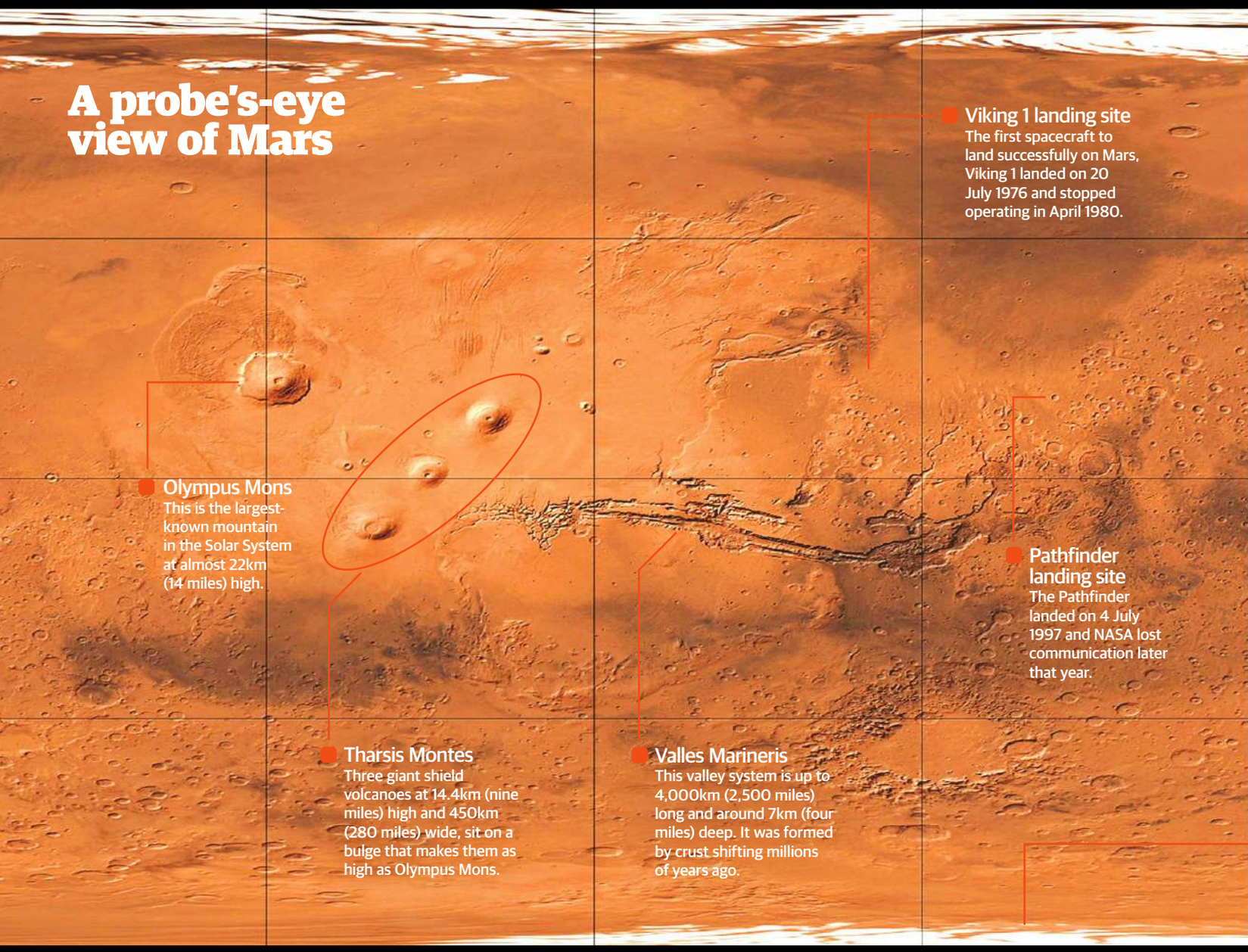
This image, taken by the Viking Orbiter from low orbit, shows the thin layer of Mars's atmosphere – less than one per cent the thickness of Earth's atmosphere

On the surface

Mars has a lot of geographical similarities with Earth, but there's a reason why we haven't found life there... yet

Thanks to the many images sent back from various probes, we know that Mars has a lot of interesting geographical features. The biggest one is that Mars has incredibly different northern and southern hemispheres. Most of the northern hemisphere is lower in elevation than the southern one (up to six kilometres or four miles lower). It also has far fewer impact craters, and is much smoother and uniform all over. Finally, the crust on the northern hemisphere appears to be much thinner than the southern hemisphere's. While astronomers aren't sure of the reasons behind this dichotomy, it involves the three main forces that have influenced the planet's surface: volcanic activity, tectonics and impacts.

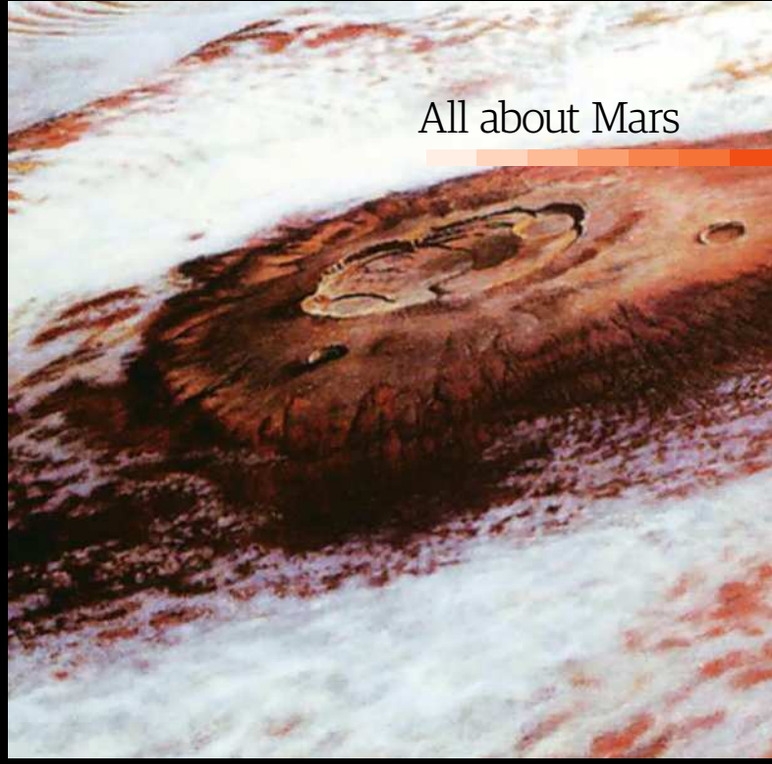
Some of the most striking features on Mars's surface are its mountains – which are all inactive volcanoes. The western edge of the southern hemisphere contains two different areas – the Tharsis bulge and the Elysium volcanic complex – each of which contain several volcanoes. The Tharsis bulge covers about 25 per cent of the planet's surface and lies seven to ten kilometres (four to six miles) above it. This includes Olympus Mons, a shield volcano that is the largest mountain in the Solar System. Up until a few years ago, scientists were sure that Mars didn't have plate tectonics like Earth. Then we discovered that there are in fact tectonics at work. Not only do features like steep cliffs and the flat walls of canyons show faults at work, but so do the fact that Mars's volcanoes are concentrated in two different areas. The huge valley system known as the Valles Marineris is the deepest in the Solar System and takes up a quarter of the



planet's circumference. It's also a plate boundary, with horizontal movement along the plates. With just one known fault as opposed to many on Earth, some believe that Mars's tectonic system is much younger.

Impact craters and basins are prevalent in Mars's southern hemisphere. The Hellas basin is the largest of these at 1,800 kilometres (1,100 miles) in diameter. The largest basins are believed to date back to a period of heavy bombardment about 3.8 billion years ago. They show evidence of erosion and also contain a lot of regolith, or soil deposits. The smaller craters are younger, and look a lot like the Moon's impact craters.

Mars has many different types of craters thanks to erosion, deposits and volcanic activity. They also contain ejecta blankets – flows formed in the soil after an impact melts ice under the planet's surface. Mars is believed to have ice underneath its surface – and there are also ice caps at the poles, the amount of which changes depending on the seasons. Because Mars has a similar tilt to the Earth, it does have four seasons – they're just longer and of varied lengths. Temperatures can get as low as minus 143 degrees Celsius (minus 225 degrees Fahrenheit) at the ice caps in the winter. The ice beneath the surface freezes and melts depending on the temperature. The atmospheric pressure on Mars is much lower than the Earth's, and it's so thin that there is very little to block the surface from the Sun's heat. There are ice clouds, probably caused when the wind kicks up dust, while one of the Red Planet's biggest weather features is dust storms, which can last up to a month.



Despite its thin atmosphere, Mars does have a layer of ice-water clouds, although the blanket lies below the planet's tallest volcano, Olympus Mons. A wave cloud due to ripples in the atmosphere is also visible

North pole
Mars's north pole contains about a third of the ice found in the Earth's Greenland ice sheet.

Viking 2 landing site
NASA's Viking 2 landed here on 3 September 1976 and operated until 11 April 1980.

Hellas Planitia
The largest visible impact crater in the Solar System is around 2,300km (1,400 miles) in diameter and 7.2km (4.4 miles) deep.

Spirit rover landing site
NASA's Spirit rover landed on 4 January 2004 and became stuck in soft soil on 1 May 2009. Communication was lost in 2010 and NASA officially ended the mission in 2011.

South pole
The south pole contains enough ice to cover the surface of the planet in a liquid layer up to 11m (36ft) deep.



Olympus Mons



Polar ice caps

Canyons, craters and deserts

Mars is home to some of the largest planetary features in the Solar System

Olympus Mons
Olympus Mons is the tallest known mountain in the Solar System at 22km (14 miles) high. It's more than twice the size of Mount Everest and is an extinct volcano.

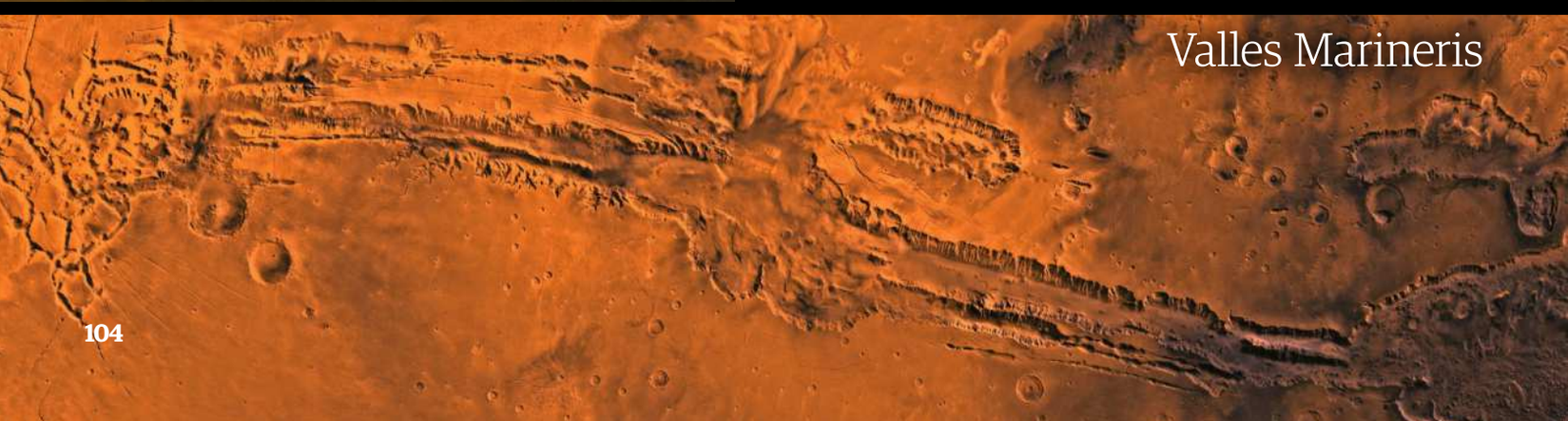
Polar ice caps
This polar ice cap on the southern end of Mars grows and wanes each year depending on the season. It is made up of both water ice and dry ice (frozen carbon dioxide).

Valles Marineris
Valles Marineris is a system of canyons located along the equator of Mars and covers almost 25 per cent of the planet's circumference. It is around 7km (four miles) deep, 200km (124 miles) wide and 4,000km (2,500 miles) long. On Earth, that would be the distance between New York and Los Angeles.

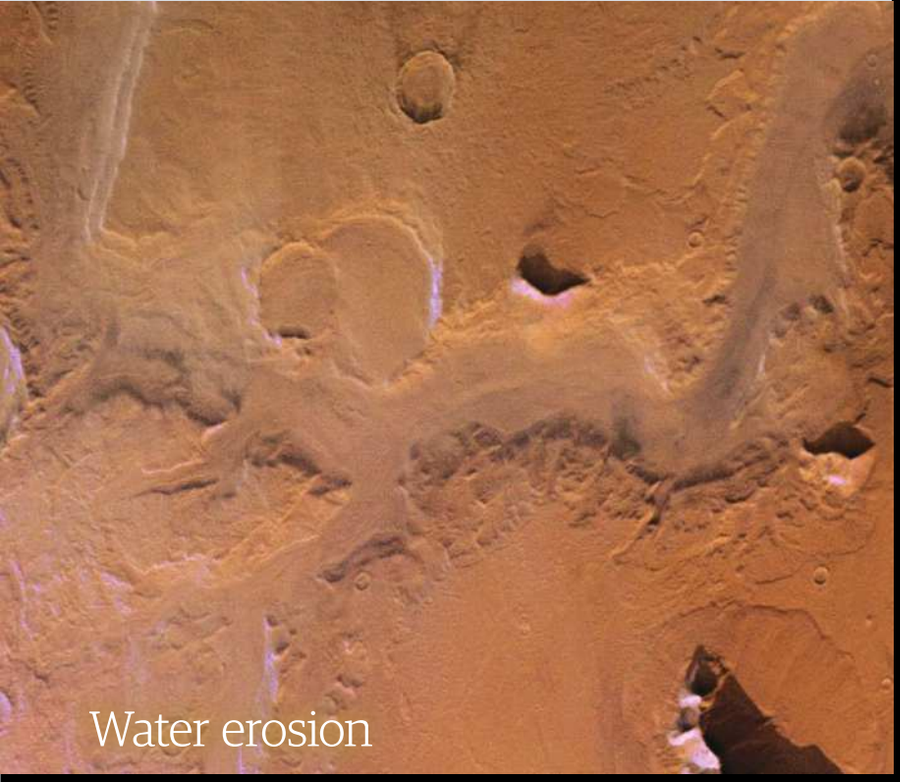
Water erosion
Reull Vallis is one of the valleys on Mars that look as if they may have been carved out by water movement. Many of these valleys contain grooves on their floors that may be rich in ice.

Sand dunes
Regolith - a mix of soil, sand, dust and broken rocks - has drifted into dunes on Mars's surface. We once thought they were stationary, but observations have shown that the dunes actually move due to prevailing winds.

Hellas Basin
The Hellas Basin is one of the biggest impact craters in the Solar System. At 2,300km (1,400 miles) in diameter, it is wider than the state of Texas.



Valles Marineris



Water erosion



Sand dunes



Hellas Basin

Mars by numbers

Fantastic figures and surprising statistics about the Red Planet

2,300km

The diameter of Mars's Hellas Basin is the same as the diameter of Pluto

2

Mars has two known satellites: the moons of Phobos and Deimos

271 years and 221 days

How long it would take you to get to Mars from Earth if you could drive there in a car at 97km/h (60mph)

14.5

Travelling at a speed of 14.5 miles per second compared to the Earth's 18.5 miles per second, Mars is slower to orbit the Sun

687 Earth days

A year on Mars is 687 Earth days, while a day on Mars is equivalent to 1.026 Earth days

37.5%

Gravity on Mars as a percentage of Earth's. If you could visit, you could jump three times as high as you can on our planet

Exploring Mars

The failure rate for exploring Mars has been high

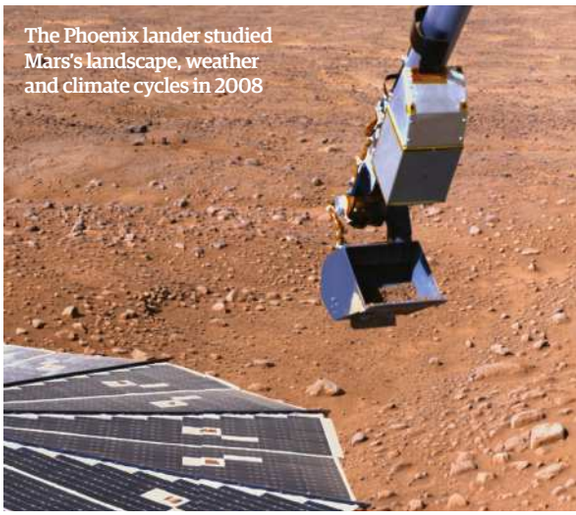
The Soviet Union, not the United States, was the first country to attempt a Mars exploration – but it was unsuccessful. The Mars 1M was just the first of many failed attempts to visit Mars. Since that first attempt in 1960, 43 different spacecraft have tried and only 14 of them completed their missions. Mars 1M had a launch failure, but other probes have been the victims of communication problems, computer malfunctions and even the planet itself. It's been so difficult to get to Mars that some have dubbed the challenge the 'Martian curse', and one journalist in the United States jokingly said that there must be a 'Galactic Ghoul' hindering our exploration efforts. So why has it proved so difficult to get there? It takes a spacecraft about seven months on average to travel the 225 million kilometres (140 million miles) to Mars. Once it reaches the planet, if the orbiter has a lander then it must successfully separate and have the lander touch down gracefully on the surface. And Mars can be unpredictable. Things like dust storms and soft soil have impeded landers, for example. But we do have to remember that most of total failures were early in our space exploration history. While there have been some memorable recent failures, including the 1999 Mars Climate Orbiter, which was pure human error. In that case, a contractor used imperial units instead of metric, which caused the probe's rocket to shut down early and send it crashing into the planet.

Currently there are three orbiters around Mars: the Mars Odyssey and Mars Reconnaissance Orbiter, both from NASA, and the ESA's Mars Express. The Opportunity rover has been on the surface since 2004, Curiosity joined it in 2012 and a new rover, Perseverance, landed in 2021. Despite the high failure rate, we'll surely continue to explore the Red Planet. It's just too fascinating to keep away.

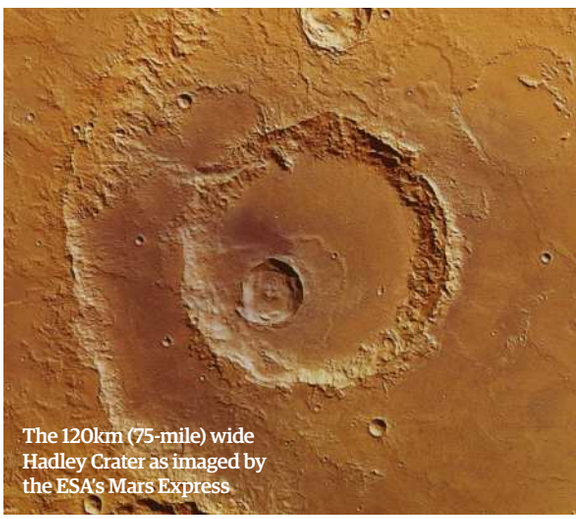


MSL launches atop a Atlas V rocket on 26 November 2011

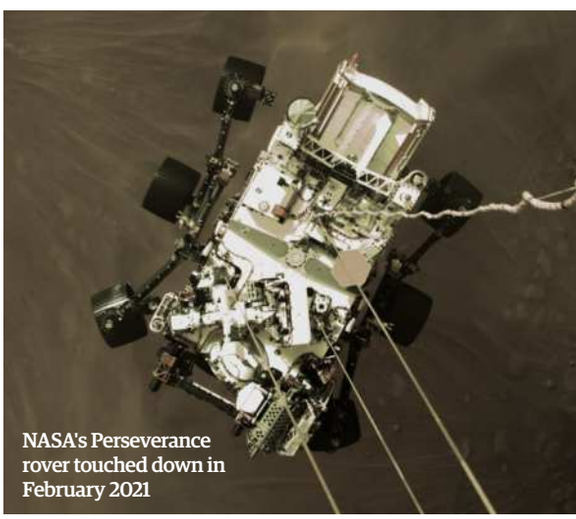
"It takes a spacecraft about seven months to travel the 225 million kilometres to Mars"



The Phoenix lander studied Mars's landscape, weather and climate cycles in 2008



The 120km (75-mile) wide Hadley Crater as imaged by the ESA's Mars Express



NASA's Perseverance rover touched down in February 2021

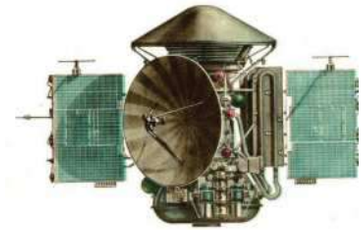
Major missions



Mars 1M
Oct 1960
These Soviet missions were the first in the quest to explore Mars. Mars 1M No 1 experienced a launch failure on 10 October 1960. Mars 1M No 2 met the same fate.



Mariner 4
28 Nov 1964-21 Dec 1967
Mariner 4 performed the first flyby and returned the first colour images of Mars. These were also the first images taken of another planet from deep space.

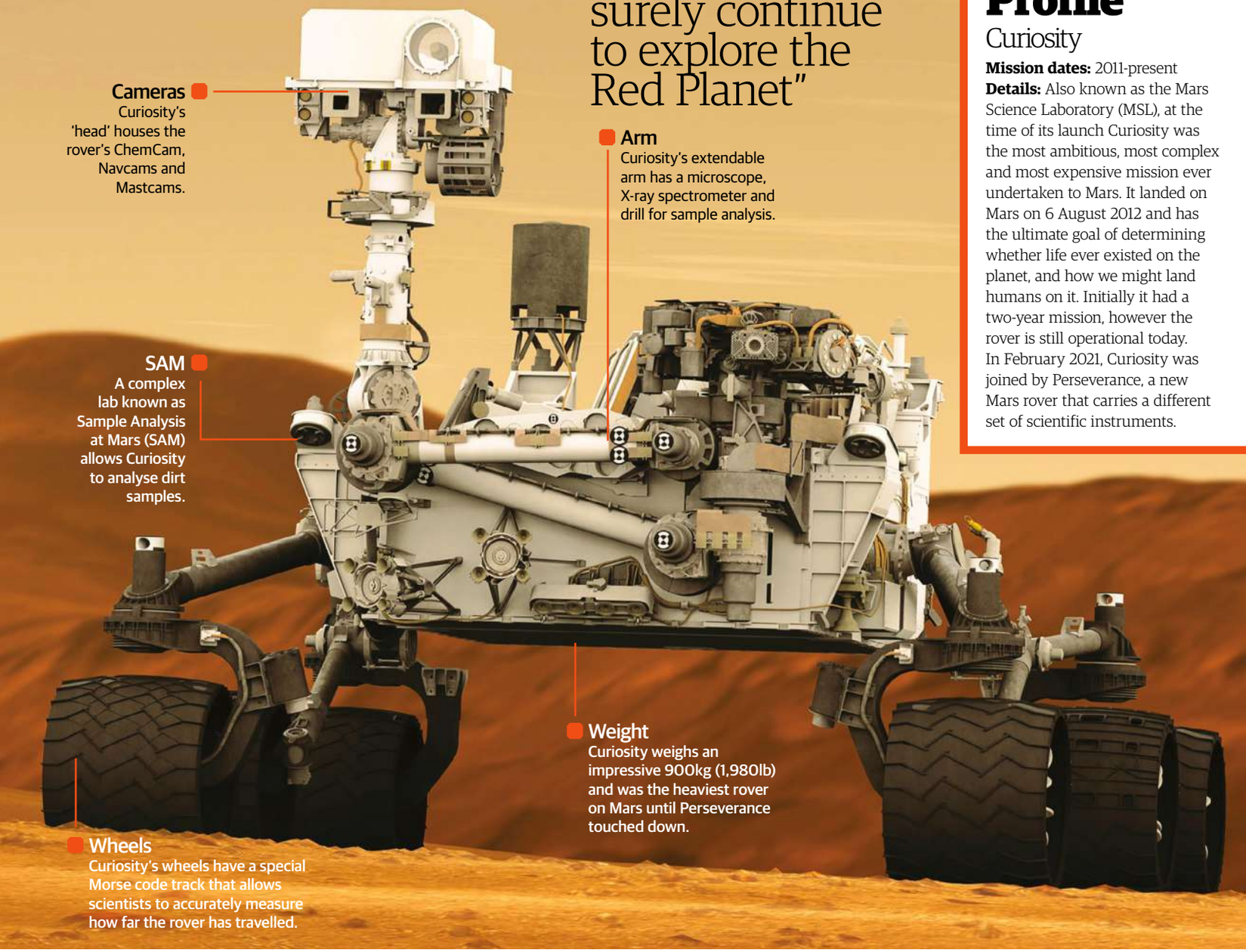


Mars 2 & 3
19 May 1971-22 Aug 1972
The Soviet-built Mars 2 became the first spacecraft to land – or rather crash – into the surface of the planet. Mars 3 had a soft landing on 2 December 1971.



Viking 1 & 2
20 Aug 1975-13 Nov 1982
Viking 1 landed softly and fully completed its mission. It also held the record for longest Mars mission until the Opportunity rover.

"Despite the high failure rate, we'll surely continue to explore the Red Planet"



Cameras
Curiosity's 'head' houses the rover's ChemCam, Navcams and Mastcams.

Arm
Curiosity's extendable arm has a microscope, X-ray spectrometer and drill for sample analysis.

SAM
A complex lab known as Sample Analysis at Mars (SAM) allows Curiosity to analyse dirt samples.

Weight
Curiosity weighs an impressive 900kg (1,980lb) and was the heaviest rover on Mars until Perseverance touched down.

Wheels
Curiosity's wheels have a special Morse code track that allows scientists to accurately measure how far the rover has travelled.

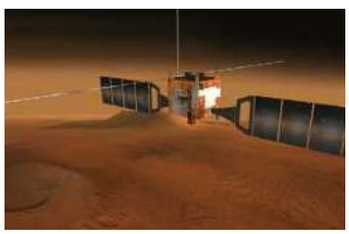
Mission Profile

Curiosity

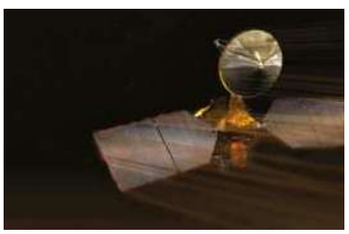
Mission dates: 2011-present
Details: Also known as the Mars Science Laboratory (MSL), at the time of its launch Curiosity was the most ambitious, most complex and most expensive mission ever undertaken to Mars. It landed on Mars on 6 August 2012 and has the ultimate goal of determining whether life ever existed on the planet, and how we might land humans on it. Initially it had a two-year mission, however the rover is still operational today. In February 2021, Curiosity was joined by Perseverance, a new Mars rover that carries a different set of scientific instruments.



Mars Polar Lander
3 Jan 1999-3 Dec 1999
The Mars Polar Lander was meant to perform soil and climatology studies on Mars, but NASA lost communication with it and it's believed to have crashed.



Mars Express Orbiter
2 Jun 2003-present
The ESA's first planetary mission consisted of the Beagle 2 lander and the Mars Express Orbiter, with the latter still operational today.



Beagle 2
2 Jun 2003-19 Dec 2003
The Beagle 2 lander was lost six days before it was due to enter the Martian atmosphere. Attempts were made to contact it, but these ended in failure.



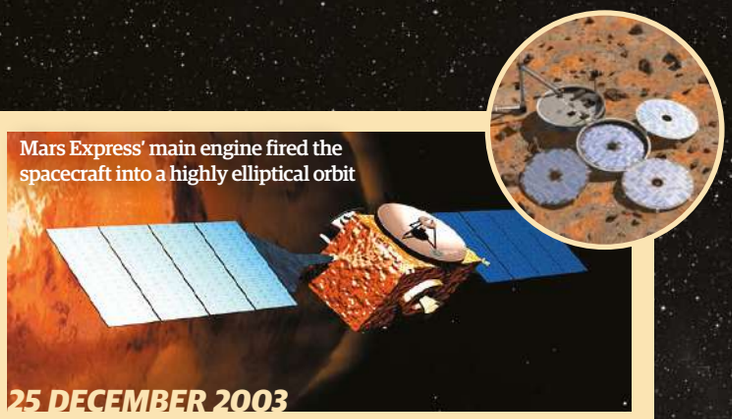
Opportunity
7 Jul 2003-10 Jun 2018
Opportunity was a rover launched shortly after its twin, Spirit, by NASA. It was still going strong up until 2018, when a dust storm silenced it.



MARS EXPRESS

Discover the important milestones throughout the life of one of the European Space Agency's most successful spacecraft

— Written by Lee Cavendish —



25 DECEMBER 2003

Arrival of Mars Express and Beagle 2

Mars Express is equipped with a sophisticated instrument suite fitted with surface/subsurface, atmosphere and plasma instruments able to reveal remarkable details about Mars. This culmination of years of ideas, construction and travelling through space all relied on Mars Express entering a safe orbit around Mars.

Launched with Mars Express was the first British-built Martian lander, Beagle 2. The lander was released from Mars Express on 19 December, six days before the mother craft entered orbit around Mars, and scientists hoped that it would uncover important clues as to Mars' ancient astrobiology. Unfortunately, contact with Beagle 2 was never made after its scheduled touchdown date and ESA declared it lost in February 2004.

30 MARCH 2004

The mysterious methane signal

Mars Express' Planetary Fourier Spectrometer (PFS) instrument picked up an unusual signal while analysing the atmosphere. The expected atmospheric candidates were seen – such as carbon monoxide and water vapour – but this unusual signal was later interpreted as being methane.

This was an exciting discovery, as methane can only survive in the atmosphere for a few hundred years. This begs the question, is there some recent volcanic activity or biological process that is replenishing the atmosphere?


Elysium Planum was one of the regions where tiny amounts of methane were detected

2004

17 MARCH 2004

Water ice found at the south pole

It was previously known that Mars has ice situated at its poles. This is not to the same extent as Earth, as Mars's polar ice is much thinner and more seasonally variable. More surprising, Mars Express' Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) instrument revealed that water ice, as well as carbon dioxide ice, is present at both the north and south poles.

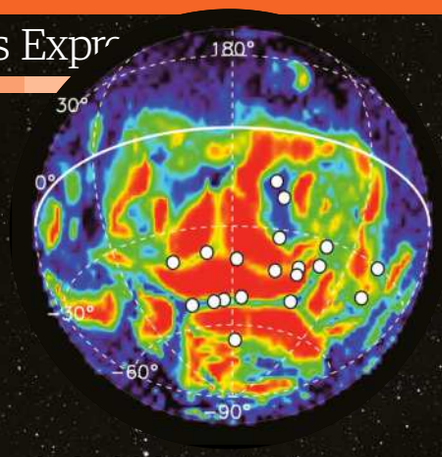
OMEGA measured the amount of sunlight and heat reflected from the poles to confirm this result. In the case of the south pole, scientists were also surprised to see vast amounts of perennial water ice encasing it.


The steep slopes, known as 'scarps', are made almost entirely of water ice

Mission Objectives

1. Provide a global, 3D, high-resolution photogeologic analysis to discover more about the surface and geology of Mars.
2. Study the subsurface structure of Mars by using radar beams. The different materials or structures sent back radar echoes, allowing scientists to produce an accurate 3D survey.
3. Construct an accurate picture of the Martian meteorology and climate by determining the atmospheric circulation and composition.
4. Study the interaction between the Red Planet's atmosphere and outer space

©ESA, Adrian Mann



11 AUGUST 2004

Aurorae scattered over Mars

Aurorae usually occur when charged particles from the solar wind collide with a planet's atmosphere at the poles due to the nature of the planet's magnetic field. When Mars Express first detected localised aurorae on Mars via the Spectroscopy for the Investigation of Characteristics of the Atmosphere of Mars (SPICAM) instrument, it cast a new light.

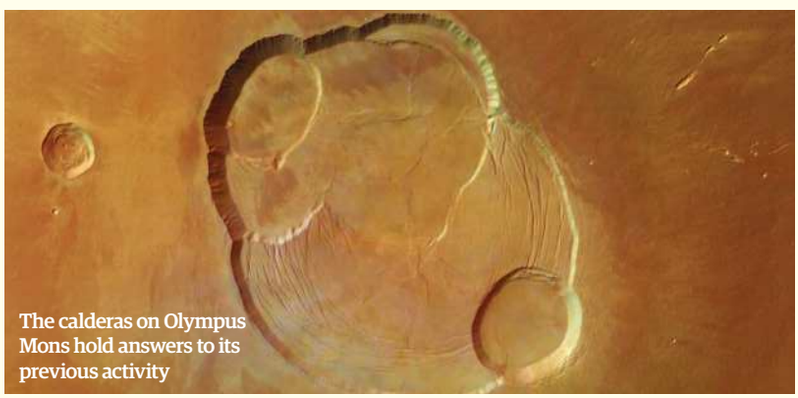
Along with NASA's Mars Global Surveyor, scientists deduced that the Martian crust produces cusp-like magnetic structures capable of concentrating the excited particles in very small regions.

23 DECEMBER 2004

The Red Planet's eruptive past

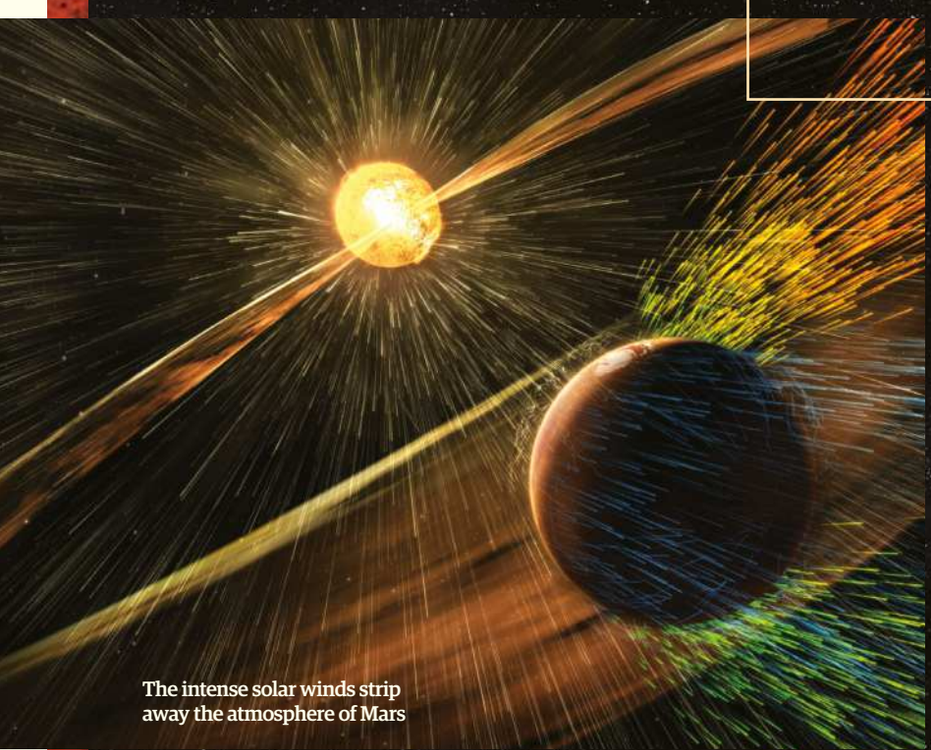
Mars is famous for having the largest volcano in the entire Solar System. Olympus Mons is 25 kilometres (15 miles) high – almost three-times taller than Mount Everest. The High Resolution Stereo Camera (HRSC) on Mars Express showed that the most massive volcanoes, including Olympus Mons, were active more recently than thought.

The analysis of Olympus Mons, along with four other major volcanoes Arsia Mons, Ascraeus Mons, Albor Tholus and Hecates Tholus show that volcanic activity could have occurred as recently as two million years ago. Scientists previously thought such activity on Mars ceased around half a billion years ago. This, along with data suggesting that the activity was also very sporadic, meant scientists had to rethink the interior and evolution of Mars based on these results.



The calderas on Olympus Mons hold answers to its previous activity

2005



The intense solar winds strip away the atmosphere of Mars

27 SEPTEMBER 2004

The depleting atmosphere

Mars was once a planet with water flowing across the surface and had a suitable atmosphere that kept it relatively warm, which could have supported life. Today, Mars is a cold, dry planet with an atmosphere 150 times lower in pressure than on Earth, so Mars Express set out to find out what happened during its evolution to transform the planet.

Mars Express' Analyser of Space Plasma and Energetic Atoms (ASPERA) instrument took valuable data about the interaction between the solar wind and the upper atmosphere and ionosphere. Data showed that in just a few minutes the upper atmosphere can alter and open a path for the solar wind to penetrate deeper into the atmosphere, interacting with water ions and causing them to escape into space.

However, this ion escape rate depends on varying solar winds and cannot fully account for the drastic depletion over the last 3.5 billion years. This means another mechanism must have been at work, possibly removing neutral atoms in the upper atmosphere. A recent theory even suggests that dust storms play a part in kicking up atoms to higher altitudes where they then escape Mars.



30 NOVEMBER 2005

The hidden, third layer in the ionosphere

Many exciting discoveries about the Martian surface came in the opening years of Mars Express, but this discovery confirmed the presence of a new, third layer in the ionosphere of the Martian atmosphere using its Mars Radio Science Experiment (MaRS).

Situated at an altitude between 65 and 110 kilometres (37 and 68 miles), the MaRS instrument discovered regions of higher densities in charged particles such as electrons. The leading theory behind the origin of this layer is thought to be collisions between the ionosphere and meteorites.

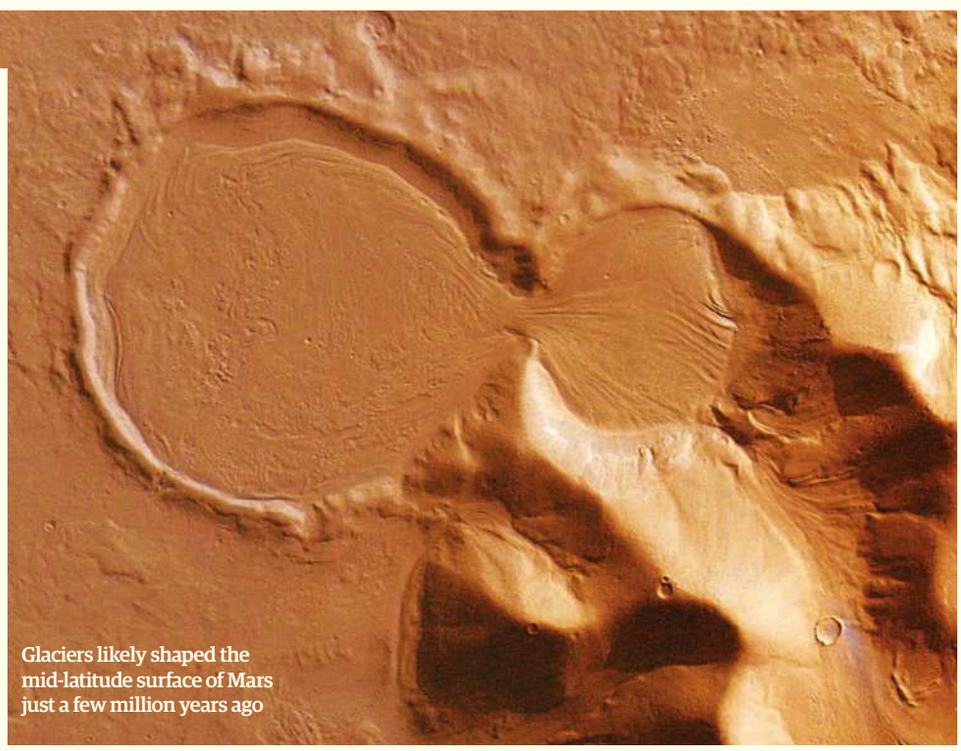
"Many exciting discoveries about the Martian surface came in the opening years of Mars Express, but this discovery found a new, third layer in the ionosphere of the Martian atmosphere"

18 MARCH 2005

Surveying former glaciers

As Mars Express swooped over the surface of Mars its High Resolution Stereo Camera (HRSC) found some intriguing traits in Mars' tropical and mid-latitude regions. Within these regions were features relating to recent and recurring glacial activity, known as debris aprons.

In a region called Promethei Terra, on the eastern rim of the Hellas Basin, there was an unusual 'hourglass'-shaped feature which caught the attention of many. Research found that it's an impact crater filled to the brim with ice and an assortment of small rocks. The lack of impact craters on the deposits indicates it's relatively young – another significant piece of evidence in determining the previous climate history of Mars.



Glaciers likely shaped the mid-latitude surface of Mars just a few million years ago

© NASA/JPL; ESA; J-C. Gérard et al.



There are copious areas where hydrated minerals reside, shown here by green dots

30 NOVEMBER 2005

Search for water boosted by locating hydrated minerals

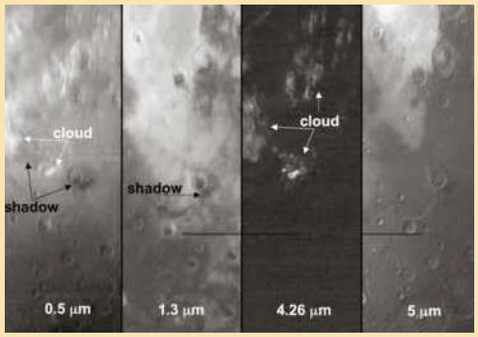
The first ever detection of hydrated minerals on Mars caused worldwide excitement. During the last 15 years of observations, OMEGA has recorded two classes of hydrated minerals, which are crystalline structures containing water. Phyllosilicates and hydrated sulphates were found over large areas, and although they are both a result of chemical alterations of rocks, they are formed in different ways. Phyllosilicates are formed from the reaction between igneous minerals and long-term exposure to water, whereas hydrated sulphates are formed from reactions with acidic water.

16 JANUARY 2008

Carbon dioxide ice clouds

Mars Express' OMEGA instrument detected carbon dioxide (CO_2) ice clouds, a unique feature of the Red Planet's climate. These clouds are formed from the freezing of carbon dioxide gas, which makes up 96 per cent of the Martian atmosphere.

These clouds were observed at wavelengths of 0.5 and 4.26 microns. This revealed that the abundance of clouds varies from Martian year to year – with one Martian year equating to 687 Earth days. In addition, these carbon dioxide clouds are large and dense enough to form shadows on the planet's surface, which suggests they are 80 kilometres (50 miles) above the surface.



2008 2009 2010

"The first-ever detection of hydrated minerals on Mars caused worldwide excitement"

3 MARCH 2010

Phobos up-close

On this date Mars Express made its closest approach of Mars' largest moon, Phobos, flying just 67 kilometres (41 miles) above its surface. During this brief window of opportunity, Mars Express was able to conduct a gravity experiment and produce some outstanding images.

Although it wasn't able to study Mars' other moon, Deimos, as closely, the information collected on Phobos was enough for astronomers to rethink its origins. Originally it was thought that these moons were captured asteroids. However, after density and mineral composition analysis, it is thought that these moons – and Phobos in particular – formed during a reaccretion of rocky material in Mars' orbit.

OCTOBER 2011 TO FEBRUARY 2012

The Solid-State problem



For a period of several months, all operations and observations of the Mars Express spacecraft were halted due to an issue with its Solid-State Mass Memory (SSMM) system.

The SSMM is vital for storing the data collected by instruments prior to its transmission back to Earth, and the spacecraft entered safe mode as it failed to successfully read and write the data to memory modules. Fortunately, in the early months of 2012, the Mars Express team were able to create a new command system that meant the data could once again be completed, observations made and the data sent back to Earth. This led to the continuation of Mars Express with its original lifespan unaltered.

28 OCTOBER 2013

The commemorative map celebrating a decade at Mars

2013 celebrated an impressive ten years of the Mars Express orbiter at Mars. This acknowledged Europe's first and finest space exploration mission and, as part of the achievement, a near-complete topographical map of the planet's surface was produced, which combined data from almost 12,500 orbits.

This map flaunts some remarkable sites on the Martian surface, courtesy of the HRSC instrument. These sights include Valles Marineris, Olympus Mons and other craters and mountains, as well as ancient river beds and lava flows.



Valles Marineris is a huge canyon that runs across Mars' equator

2011 2012 2013 2014 2015

16 JANUARY 2015

Beagle 2 found

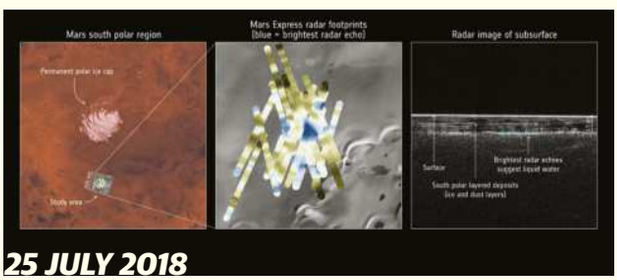
More than ten years after its disappearance, the long-lost Beagle 2 lander was found courtesy of NASA's Mars Reconnaissance Orbiter's (MRO).

"Not knowing what happened to Beagle 2 remained a nagging worry. Understanding now that Beagle 2 made it all the way down to the surface is excellent news," said Rudolf Schmidt, ESA's Mars Express project manager at the time. But if it landed successfully, where did it go wrong?

Images from the MRO's HiRISE (High Resolution Imaging Science Experiment) camera suggest that only three of its four solar panels were deployed. This couldn't supply enough power to allow the radio antenna to transmit data and communicate with Earth.



The slight reflective signal was deduced to be the missing Beagle 2



25 JULY 2018

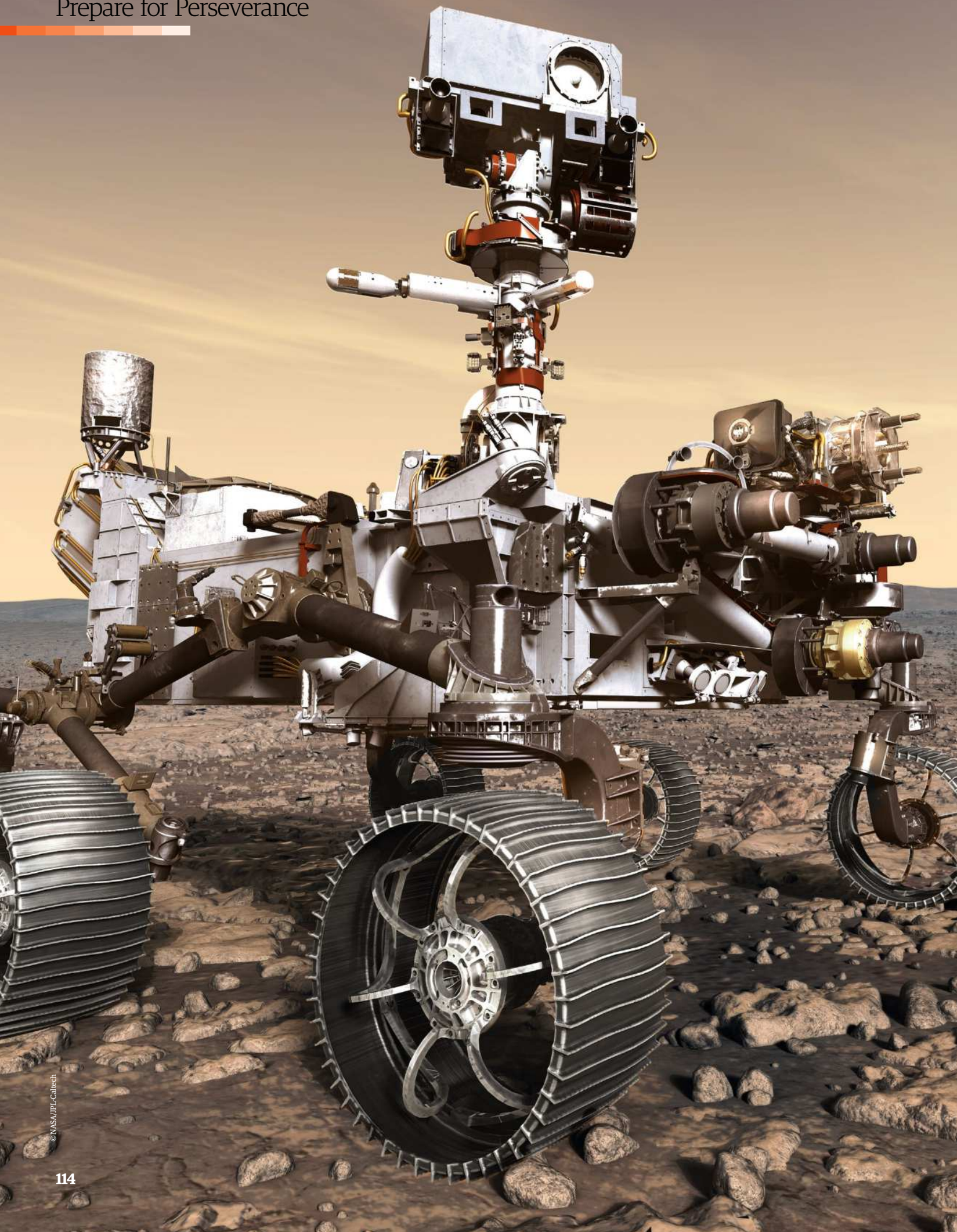
Hidden liquid water found at the south pole

Almost 15 years later, Mars Express continues to get the scientific community excited – a recent discovery found evidence for liquid water hidden under layers of ice and dust in the south pole.

The Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument sent radar pulses towards the surface and measured the timing and strength of the returning pulses to determine that a body of water exists about 1.5 kilometres (one mile) below the south polar region's surface and is around 20 kilometres (12 miles) wide.

This sort of discovery doesn't only make astronomers think about Mars' ancient climate several billions of years ago, it raises tantalising thoughts to whether life could ever have existed here.

© NASA/ESA



© NASA/JPL-Caltech

PREPARE FOR PERSEVERANCE

THE NEXT MARTIAN ROVER

Now it has touched down, NASA's new craft will hunt for signs of past microbial life, cache rock and dig for soil samples – all while preparing for human exploration of the Red Planet

Reported by Lee Cavendish

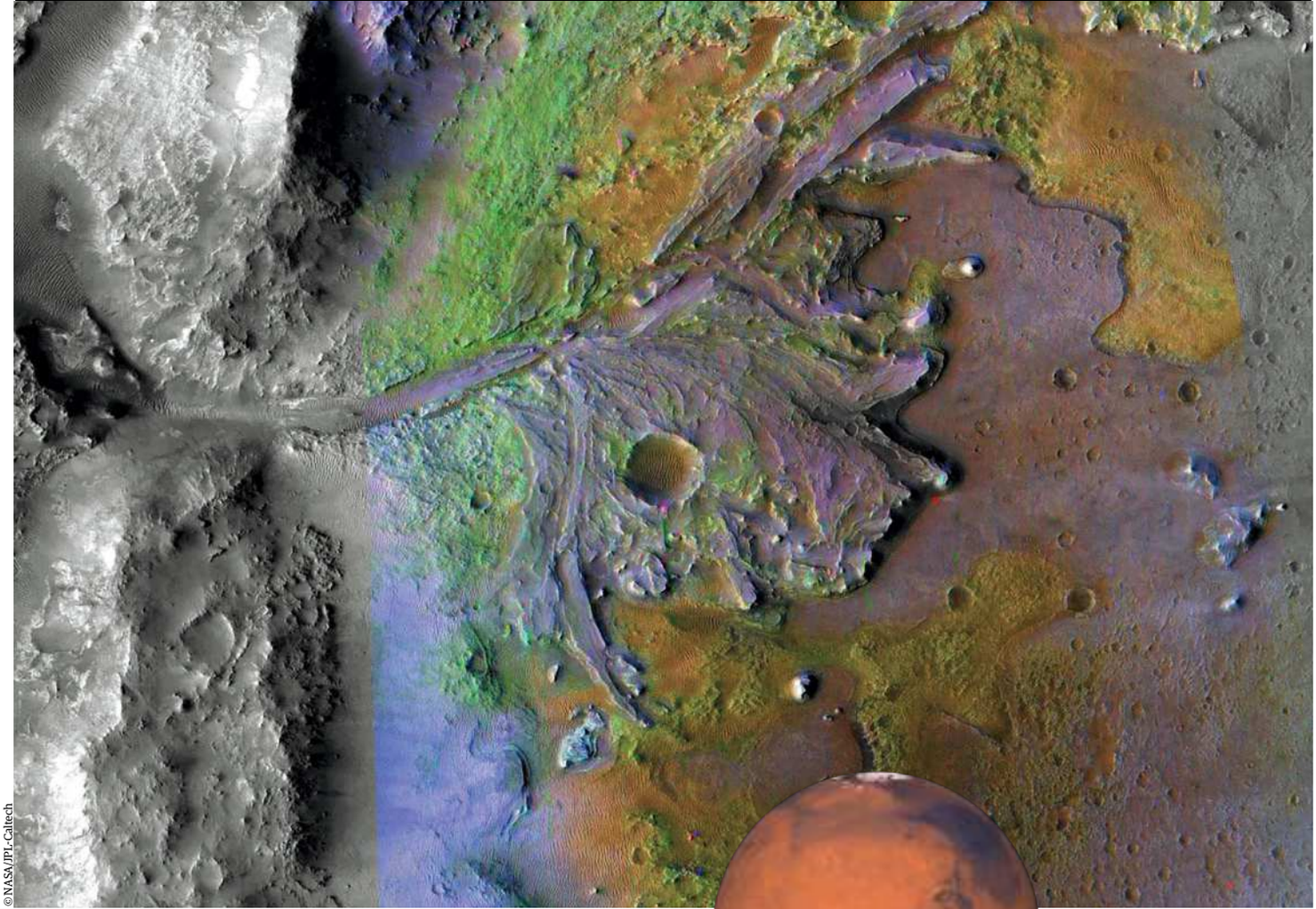


Meet the new Martian rover from NASA, Perseverance. This next-generation explorer was built upon the successes of its predecessors Spirit, Opportunity and the Mars Science Laboratory (MSL), also known as Curiosity. All of these robot explorers have worked towards helping us better understand the planet next door, Mars, and in the wider scope of science understanding the past biology and geology of other worlds. Now, the Mars 2020 mission's Perseverance rover is looking to go even further.

The mission launched on 30 July 2020, with a landing date of 18 February 2021. It flew on top of an Atlas V 541 rocket, which also launched Curiosity and InSight, from Cape Canaveral Air Force Station in Florida. However, the rover was not travelling alone. Alongside Perseverance was a first-of-its-kind demonstration aircraft called the Mars Helicopter – more affectionately nicknamed Ingenuity. Now, following a half-a-year voyage through space, the duo is ready to get to work at their destination, Mars' Jezero crater – located on the western edge of Isidis Planitia, just north of the Martian equator.

After the much-fretted 'seven minutes of terror', where mission staff held their breath for seven minutes as the rover underwent its atmospheric descent and landing, the rover has only just began its primary mission duration of one Mars year – 687 days in Earth time. During this time Perseverance will inspect the Martian surface for signs of ancient life, characterise its geology and climate, prepare for future human exploration and collect samples of rock for a future return mission.

"Perseverance is the most sophisticated and complex rover mission we've ever sent to Mars. Perseverance has a new and updated science payload that makes it better suited for searching for ancient signs of life in the rock record of Mars than any previous Mars mission," explains one of the Mars 2020 deputy project scientists, Dr Kathryn Stack Morgan when we spoke to them ahead of the mission launch. "Previous rovers have scratched, brushed and drilled Mars rocks before, but Perseverance is the first rover that will collect and cache intact rock samples. Perseverance's sample caching system and sample tubes were



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designed to ensure the scientific integrity of these samples for a potential future return to Earth, and the mission has met unprecedented requirements for biological cleanliness and contamination control to accomplish this."

"One of Mars 2020's key objectives is to collect and cache a set of samples that could be returned to Earth by a set of future missions. This concept is called Mars Sample Return, and it has been a goal in the planetary science community for a very long time," explains Mars 2020's other deputy project scientist, Dr Ken Williford. "There are many scientific and technical reasons to return samples from Mars, but one of the most exciting is the opportunity to use our most powerful laboratories on Earth to look for evidence of past life."

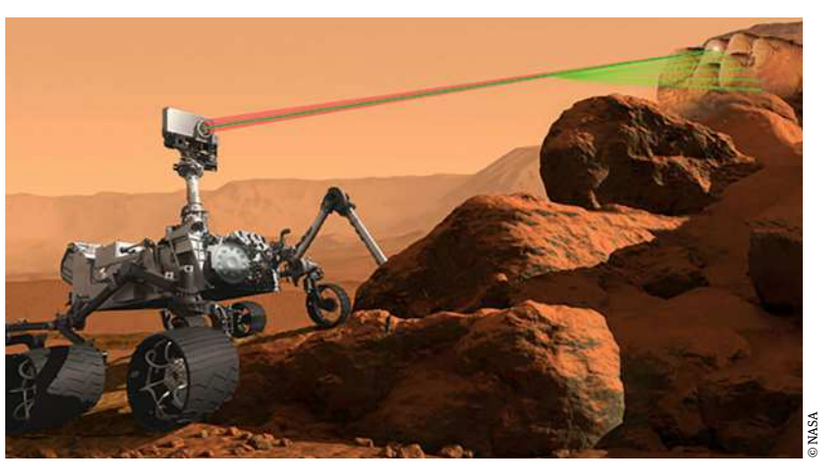
This innovation would not have been possible without the help of the missions that came before. The most obvious and recent example of this is Curiosity, and the two rovers share an almost-identical appearance. NASA has a habit of recycling space probe designs – for example, the currently operational InSight lander uses a design taken from the 2007 Phoenix lander. As the age-old saying goes: if it isn't broken, don't fix it.

When asked what the visual differences are between Perseverance and Curiosity, Morgan replies: "Perseverance has redesigned thicker and sturdier wheels compared to Curiosity, with a different tread style, and it's one of the most obvious visual differences between the two. The Perseverance turret at the end of the rover's arm is also larger and heavier than Curiosity's turret."

It's possible for more invested admirers to spot the differences, but to the untrained eye the updates are hard to take notice of. Morgan explains the advantages of using an essentially identical layout: "The use of build-to-print designs from the Curiosity rover and its landing system allowed Mars 2020 to focus its resources on the mission's new elements and new technology.

"Perseverance has a new and updated science payload compared to Curiosity. The Mastcam-Z and SuperCam instruments build on heritage from Curiosity's Mastcam and ChemCam instruments, but other Perseverance instruments – like PIXL and the SHERLOC spectrometer – are entirely new. Curiosity measures chemistry, mineralogy and the organic content of rock samples in a 'bulk' way from powdered drill fines. In contrast, Perseverance's PIXL and SHERLOC instruments allow us to produce detailed maps of chemistry, mineralogy, organics and texture without grinding up the rocks."

Seven new scientific instruments – including the aforementioned Planetary Instrument for X-ray Lithochemistry (PIXL), Scanning Habitable Environments with Raman and Luminescence for



© NASA

Above: NASA's Mars Reconnaissance Orbiter was watching over Jezero crater ahead of the rover's arrival

Right: The SuperCam will scrutinise the Red Planet's geology with unprecedented precision

Organics and Chemicals (SHERLOC) spectrometer, SuperCam and Mastcam-Z – will explore the geology of the Jezero crater landing site, assess its history of water and habitability, search for signs of past life and snap some more of those Mars selfies that everybody loves so much.

One experiment that will contribute to the Mars 2020 project, but will separate from the rover on arrival, is the Mars Helicopter. In April 2020 it was named 'Ingenuity' by a student from Tuscaloosa County High School in Northport, Alabama. It's purely a demonstration experiment. It is intended to become the first aircraft to execute powered flight on another planet, and if it works it will be a truly remarkable feat of engineering. Ingenuity will inform future innovative missions about flight on Mars, where the gravity is roughly a third of the strength of Earth's. The atmospheric density at Mars' surface level is just one per cent of Earth's at sea level, so there have always been questions about how these alien conditions on Mars will alter aircraft flight performance.

"Rather than supporting Perseverance's science mission, the helicopter is meant to pave the way for future Mars exploration. Perseverance's cameras will be important to select a safe launch and landing area for the helicopter," says Williford. "If all goes well, we should be able to capture an exciting image of the helicopter in flight!"

With this outstanding arsenal of investigative apparatus the Mars 2020 mission is well equipped to reveal the secrets of Jezero crater. But why this Martian site in particular?

"Jezero crater was chosen as the landing site for the Perseverance rover because it contains evidence of an ancient lake and delta that we believe was once habitable," says Morgan. "Delta

> "PERSEVERANCE IS BETTER SUITED FOR SEARCHING FOR ANCIENT SIGNS OF LIFE THAN ANY PREVIOUS MARS MISSION" KATHRYN STACK MORGAN

Ingenuity: meet the Mars Helicopter

The success of this prototype could transform planetary exploration forever

Mass
1.8 kilograms (four pounds)

Rotor blade span
Approximately 1.2 metres (four feet)

Length of mission
One or more flights within 30 days

Propulsion method
Counter-rotating blades that spin at about 2,400 revolutions per minute (rpm)

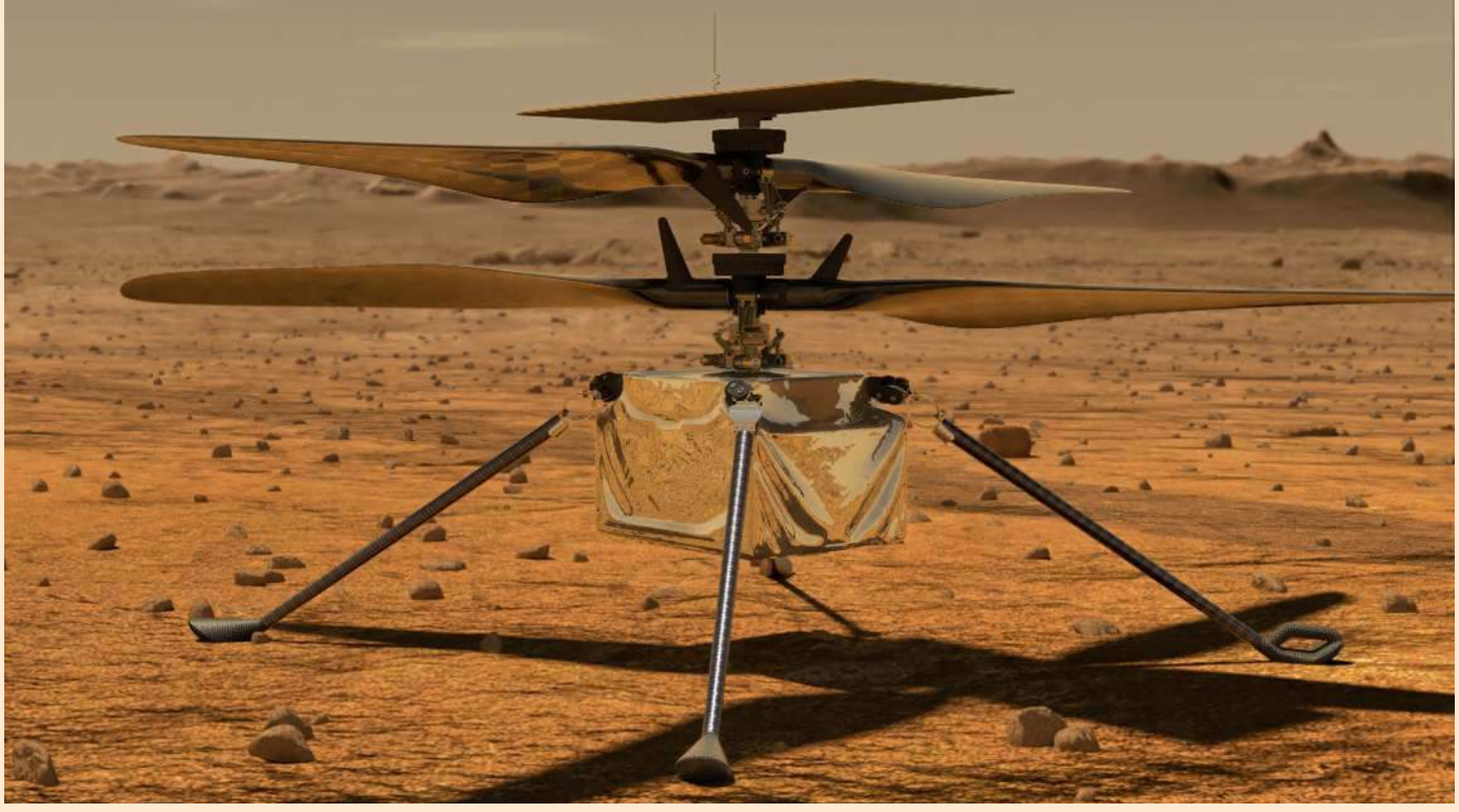
Key objective
The first-ever technology demonstration of powered flight on Mars

Onboard equipment
Navigation sensors, computers and two cameras: one colour and one black and white

Landing site
Jezero crater – the helicopter originally resided inside the Perseverance rover

Height
Approximately 0.5 metres (19 inches)

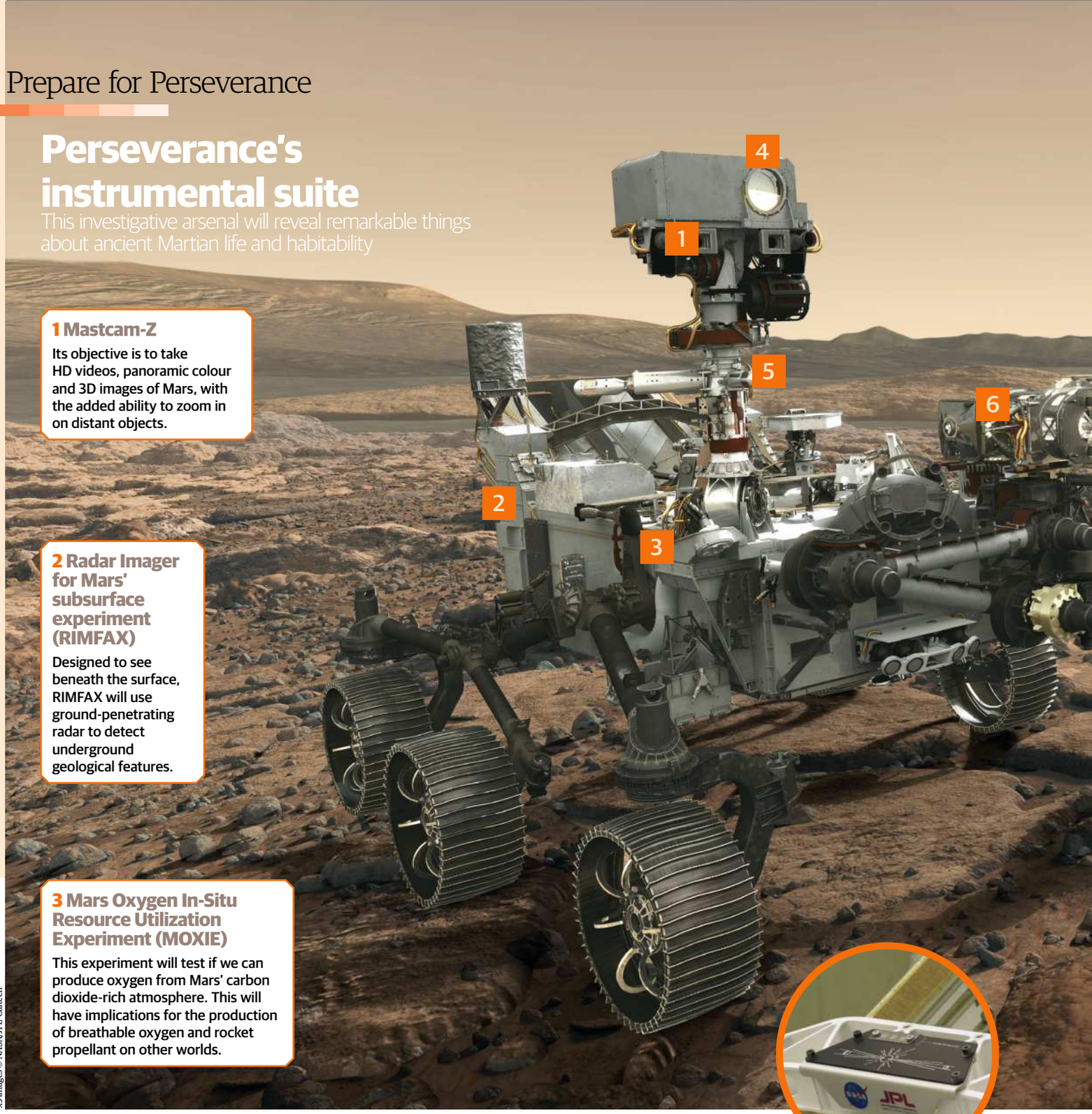
Power system
Purely solar-powered



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Perseverance's instrumental suite

This investigative arsenal will reveal remarkable things about ancient Martian life and habitability



1 Mastcam-Z

Its objective is to take HD videos, panoramic colour and 3D images of Mars, with the added ability to zoom in on distant objects.

2 Radar Imager for Mars' subsurface experiment (RIMFAX)

Designed to see beneath the surface, RIMFAX will use ground-penetrating radar to detect underground geological features.

3 Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE)

This experiment will test if we can produce oxygen from Mars' carbon dioxide-rich atmosphere. This will have implications for the production of breathable oxygen and rocket propellant on other worlds.

x3 images © NASA/JPL-Caltech

and lake sediments on Earth are known to be great preservers of organic matter and evidence of life, and we hope that signs of ancient Martian life may be preserved in the rocks exposed in Jezero crater."

When looking back at the Mars Exploration Rovers, Spirit and Opportunity, and reminiscing about their journeys through Gusev crater and Meridiani Planum respectively, they both followed the water. Their main objective was to determine whether Mars was once a wet planet or not. Together they contributed pivotal evidence to the popular hypothesis that Mars had oceans, lakes and a warmer atmosphere over 3 billion years ago. A host of rovers and orbiters were fundamental in coming to this conclusion. The European Space Agency's Mars Express orbiter and NASA's Mars Reconnaissance Orbiter have even suggested water ice still exists at the planet's poles.

Now the Mars 2020 Perseverance rover is able to build upon this amazing legacy of discovery and focus on whether there was ever ancient life on Mars. It is generally agreed that a warm and wet planet is ideal for life as we know it to arise – which Mars once was. With Jezero crater, as a former lake and delta, being an excellent candidate to scrutinise, scientists may finally be able to answer the all-important question of whether there has ever been life elsewhere in the Solar System.

"If we see chemical elements, minerals and organic molecules that tend to be associated with life, and especially if we see these things arranged in spatial patterns that suggest biology, this could be evidence of ancient life on Mars," says Williford.

It could be the case that in the near future humans will be walking around on Mars. NASA and other global space agencies and private companies are currently looking to visit, inhabit and colonise the Red Planet. Although this will all happen in small stages over the next few decades, it is NASA's



4 SuperCam

SuperCam will search for signs of ancient life by analysing the chemical composition of rocks and soil, even to the degree it can identify their atomic and molecular make-up.

5 Mars Environmental Dynamics Analyzer (MEDA)

The local weather will be analysed with MEDA, including wind speed and direction, humidity, temperature and the dust in the atmosphere.

7

6 Planetary Instrument for X-ray Lithochemistry (PIXL)

PIXL includes an X-ray spectrometer that will identify the chemical elements residing in rocks in incredibly precise detail.

7 Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC)

Consisting of spectrometers, a laser and a camera, SHERLOC will search for minerals, organic molecules and potential biosignatures in Jezero crater.

Prepare for Perseverance

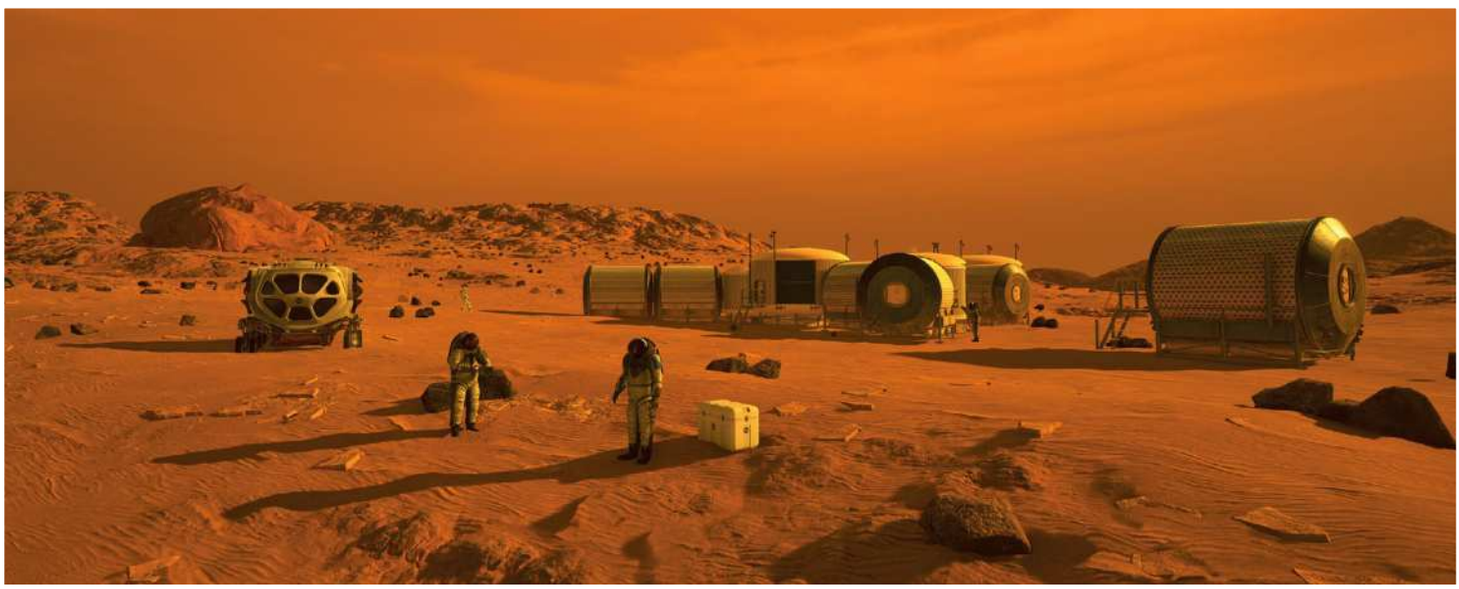
Below: Perseverance's MOXIE and MEDA instruments will return valuable data for the future human exploration of Mars

current intention to go back to the Moon in the near future and then onward to Mars. Perseverance will assist in this dream of interplanetary exploration.

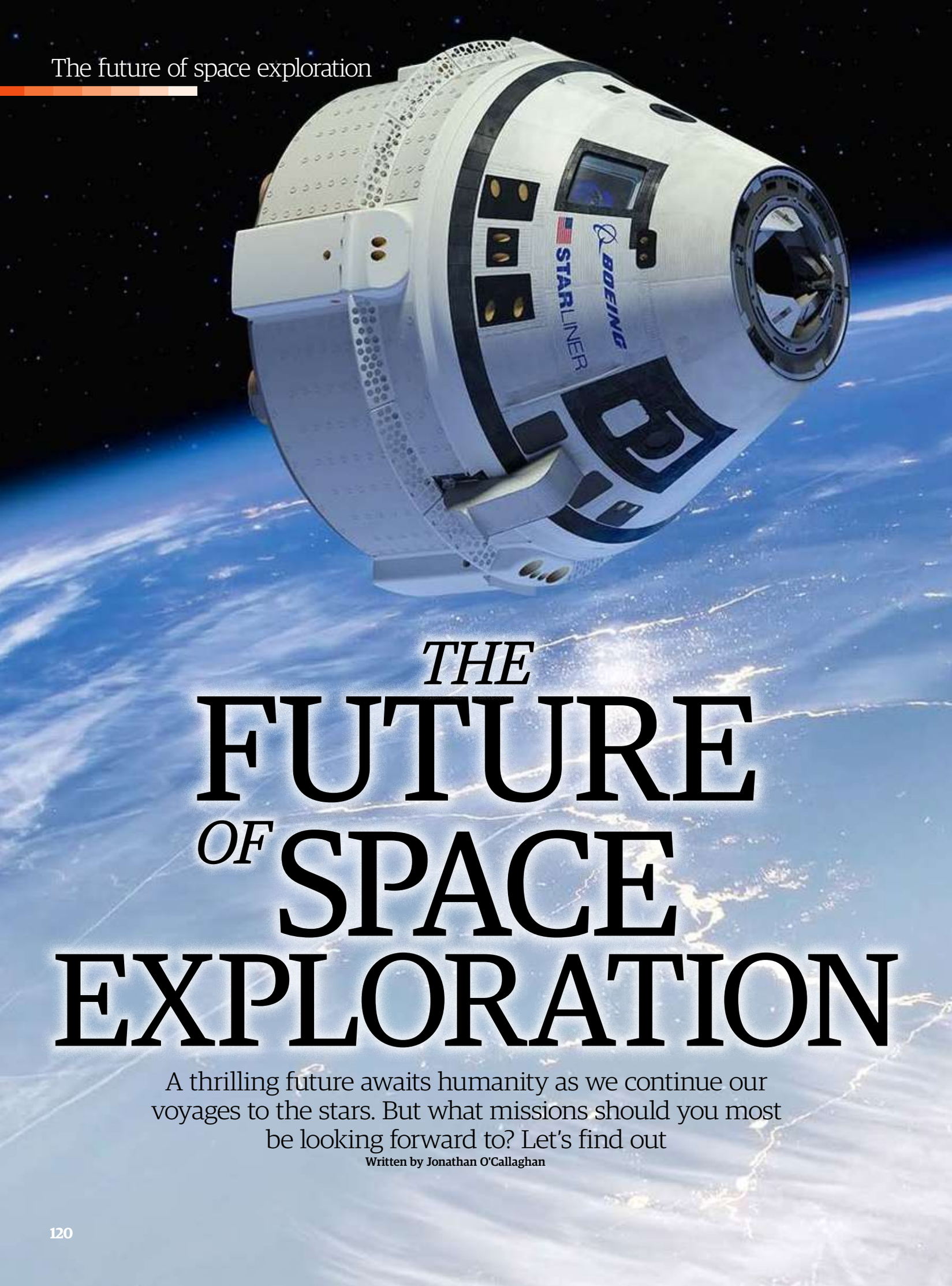
As Williford explains, Mars 2020 "has a weather station called MEDA that is contributed by Spain and will improve our understanding of surface conditions that astronauts would experience. We have an instrument called MOXIE that takes in carbon dioxide from the Martian atmosphere and converts it to oxygen."

As seen with previous NASA missions, the public have once again been able to register to become a part of this endeavour. Similar to the space agency's past InSight and Parker Solar Probe mission launches, NASA created the 'Send Your Name To Mars' campaign, which has resulted in 10,932,295 people having their names stencilled onto three fingernail-sized silicon chips by electron beams. These three chips were attached to an anodised plate which also had a laser-etched graphic depicting Earth and Mars on either side of the Sun as it shines on both planets – akin to some depictions of the Golden Records sent aboard NASA's Voyager space probes. This remarkable rover bears the expectations of over 10 million people on its robotic shoulders, but if its predecessors are anything to go by, this mission will reap some groundbreaking results for many Earth years to come and will pioneer future missions to even greater heights.

"RATHER THAN SUPPORTING PERSEVERANCE, THE HELICOPTER IS MEANT TO PAVE THE WAY FOR FUTURE MARS EXPLORATION" KEN WILLIFORD



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THE FUTURE OF SPACE EXPLORATION

A thrilling future awaits humanity as we continue our voyages to the stars. But what missions should you most be looking forward to? Let's find out

Written by Jonathan O'Callaghan



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Commercial competitors

The rival companies taking on SpaceX

SpaceX is not the only commercial space company with plans for human spaceflight. Its most prominent competitor is Boeing, a stalwart of the US aerospace industry, which is designing its own vehicle called Starliner – but delays have pushed its potential first flight with humans back to 2022. Elsewhere, Amazon founder Jeff Bezos has his own space company, called Blue Origin, that is hoping to begin short minutes-long hops into space with its New Shepard vehicle soon, before one day launching to orbit. And Richard Branson's Virgin Galactic hopes to start offering short flights into space on its space plane, perhaps also in 2022.

Space X

This pioneering US company looks set for bigger and better achievements in the near future

In the world of commercial space travel, SpaceX is king. Founded in 2002 by the South African/Canadian/American entrepreneur Elon Musk, the company has grown into a behemoth of the space industry, and is now arguably the biggest commercial space company in existence.

In May 2020, the company achieved its biggest feat yet. It launched humans into space for the first time in its Crew Dragon spacecraft, on a Falcon 9 rocket, the first commercial human spaceflight to orbit in history. Now, the company has its sights set on even grander goals. The Demo-2 mission, which took two astronauts to the International Space Station (ISS), was followed up by the four-person Crew-1 mission in November. In March 2021, the Crew-2 mission took a further four astronauts to the ISS – including the first European astronaut on a commercial mission, Thomas Pesquet.

But perhaps of more excitement will be what comes next. SpaceX has already signed up four paying space tourists to fly on its Crew Dragon vehicle to the ISS, at a cost of $55 million (£40 million) per ticket. These four people will not be the first space tourists – eight have flown to space before on Russia's Soyuz spacecraft – but this could be the start of an exciting new era. SpaceX is expected to begin more regular trips to Earth orbit, which could include destinations aside from the ISS. These could be private space hotels, being designed by companies such as Axiom Space in Houston, Texas, to even just simple jaunts into orbit, flying around our planet before returning again with a splash-down landing in the ocean.

With Crew Dragon, a clear path to more widespread space travel – initially for the very rich, but perhaps later for people of more means – can be seen. But SpaceX isn't stopping there; it's already building the next vehicle it hopes will take the next great leap with human space flight.

Called Starship, this vehicle is designed by SpaceX to transport up to 100 people at a time into space, compared to a maximum capacity of seven on Crew Dragon. Designed like something out of science fiction, it will launch atop a large 'booster' called Super Heavy. Together, both will be the largest rocket in history, eclipsing NASA's Saturn V rocket that took astronauts to the Moon.

SpaceX envisages that Starship could return humans to the Moon, and NASA has given SpaceX funding to investigate this possibility. But the end goal is to use the vehicle to reach Mars, a key goal for Elon Musk. He wants to send enough Starship vehicles to Mars to create a permanent human settlement there, one that anyone could move to. For now, SpaceX will continue launching humans on Crew Dragon, which is no mean feat in itself. But who knows what the future might hold...

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James Webb Space Telescope

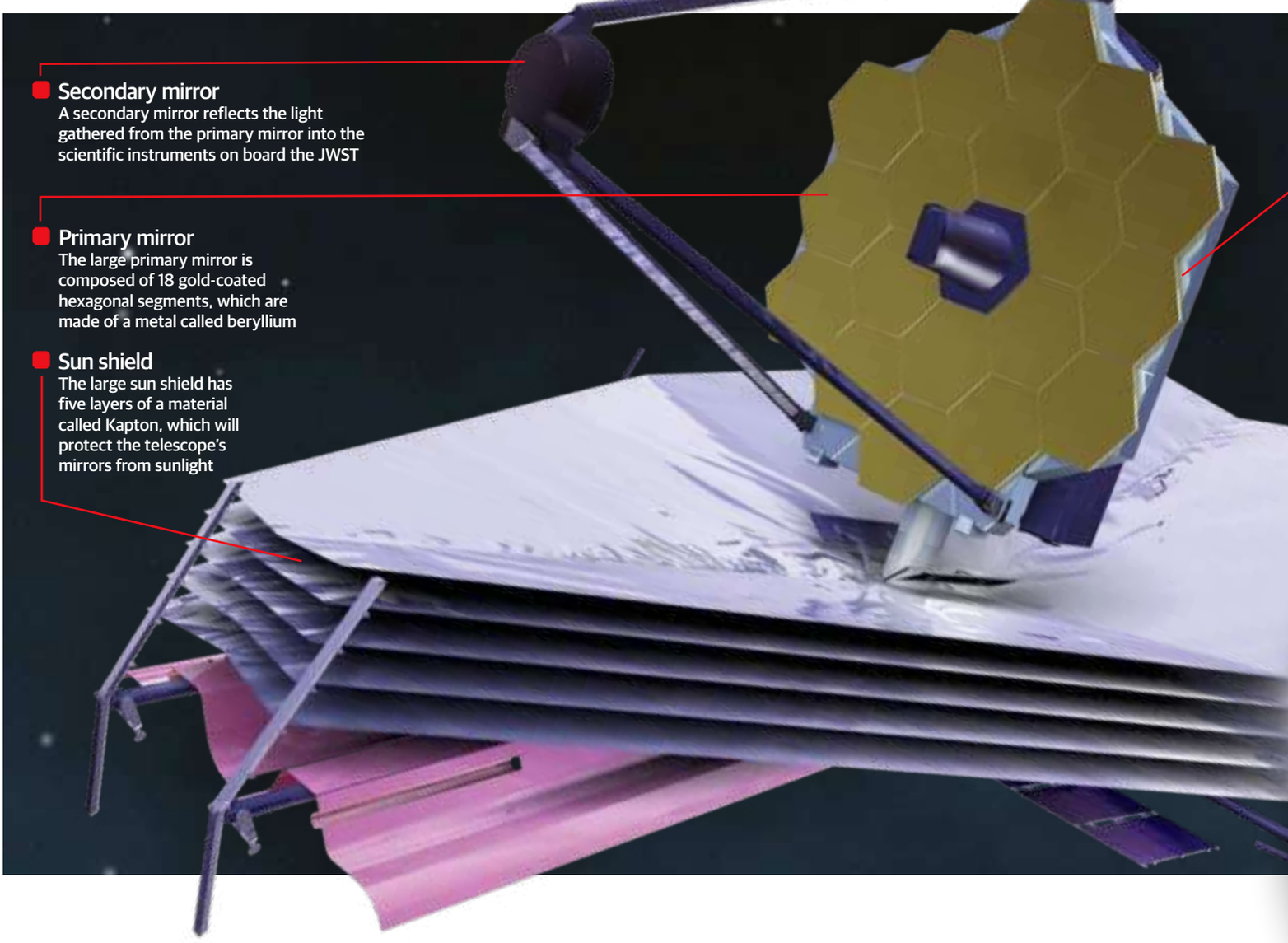
This new telescope, unlike anything ever seen before, is about to unlock the mysteries of the universe

Here's a challenge: name a telescope. What did you pick? We'd wager you probably opted for NASA's Hubble Space Telescope, which is, of course, one of the most famous telescopes in history. But in a year or two, one might wager a different answer might more readily spring to mind when you hear that question: the James Webb Space Telescope (JWST).

The JWST has been somewhat of a running joke in astronomy. First discussed in 1996 as a successor to Hubble – which was only launched in 1990, but these things need to be planned ahead – the telescope was originally set to launch in 2010. Fast forward to 2021 and, billions of dollars behind the schedule, it was finally able to reach space.

After years of waiting, the telescope was launched on a European Ariane 5 rocket on 25 December 2021. After launch, the telescope headed to its remote location; unlike Hubble, which is in Earth's orbit, the JWST is placed 1.5 million kilometres from Earth, at a point of gravitational stability beyond the orbit of the Moon called Lagrange Point 2. With a primary mirror 6.5 metres across, the JWST is the largest telescope ever launched into space. This mirror is composed of 18 hexagonal gold-coated mirror segments, which combine to create a single vast honeycomb design. The telescope was launched 'folded up', before it unfurled in space on 24 January 2022. It still needs to finish testing out its systems before it begins its mission, which will take place in June.

At the base of the telescope is a vast tennis court-sized sunshade, which will stop light from the Sun from reaching the mirror. This will enable the JWST to turn its gaze upon the universe, and astronomers are thrilled at what it might be able to observe. Rather than looking at visible and ultraviolet light like Hubble, JWST will study the universe in infrared. This will allow it to study many more cosmic objects than any telescope before. This will include planetary systems around stars in the hunt for other habitable worlds, and galaxies dating back to the universe's earliest moments. The telescope should be able to see back in time to just 100 million to 250 million years or so after the Big Bang.



The JWST will also aim to study the atmospheres of exoplanets, looking for any signs of life. This could include systems such as TRAPPIST-1, an exciting world of seven rocky planets orbiting a red dwarf star just 39 light years from our planet. The telescope will also be used to look for larger planets, like so-called mini-Neptunes and gas giants, to understand better how they form. By probing the universe's earliest moments, astronomers are hoping the JWST will be able to see the moments that galaxies began to form, including how they grew supermassive black holes at their centres. The telescope could also see the formation of planets themselves, peering through dust and gas that had previously blocked our view.

Even in our own Solar System, the JWST will be able to make some fascinating discoveries. It will be able to study the planets in our outer Solar System, and even look at comets and asteroids in unprecedented detail. It could even study some moons in the Solar System, like Saturn's Enceladus, and help in the hunt for life. The JWST is, without a doubt, the most ambitious telescope that has ever been launched into space. But, providing everything goes smoothly with the launch, it will also be the most incredible such tool we have launched. With its unprecedented capabilities, the JWST is about to open up the universe like never before. Who knows what it might discover.



x2 © Wiki

JWST BY THE NUMBERS

Stats and facts about the world's greatest space telescope

4 The JWST has four science instruments on board

6,200 kilograms The total mass of the JWST

10 YEARS It could operate for a decade or longer in space

Its mirror is **6.25** times bigger than Hubble's

1.5 million Number of kilometres it will be placed from Earth

-220 Celsius The operating temperature of the telescope

Return to the Moon

For years, the Moon has fallen our of favour, but a new wave of lunar exploration is now on the horizon

As our closest celestial neighbour, the Moon rightly holds a great allure. It is the nearest alien world we can visit, allowing us to learn more about our Solar System – and even our own planet.

In the 1960s and 1970s, the Moon was the focus in the space race between the US and the Soviet Union, with 12 Americans setting foot on its surface in NASA's Apollo programme. Now a new era of lunar exploration is beginning, but this time it's not just nations that are planning missions there, but commercial companies too. Soon, we could see a second attempt by India to land on the Moon with its Chandrayaan-3 mission, after Chandrayaan-2's Vikram Lander crashed in 2019. Russia also hopes

> "A new era of lunar exploration is beginning"

to reach the Moon again, with its Luna-25 spacecraft set to touch down at the Moon's south pole.

Elsewhere, several private companies including Intuitive Machines and Astrobotic are hoping to launch landers to the Moon, with the help of funding from NASA. They will carry with them other smaller commercial missions, with a variety of goals. Farther in the future, the return of humans to the Moon is something on the agenda. NASA has been hoping to do this with its Artemis programme, a new project to send men and women to the Moon, this time to stay on longer missions, rather than the short Apollo missions that lasted just a few days. Originally scheduled for 2024, it's now thought Artemis – if it happens – will be later this decade.

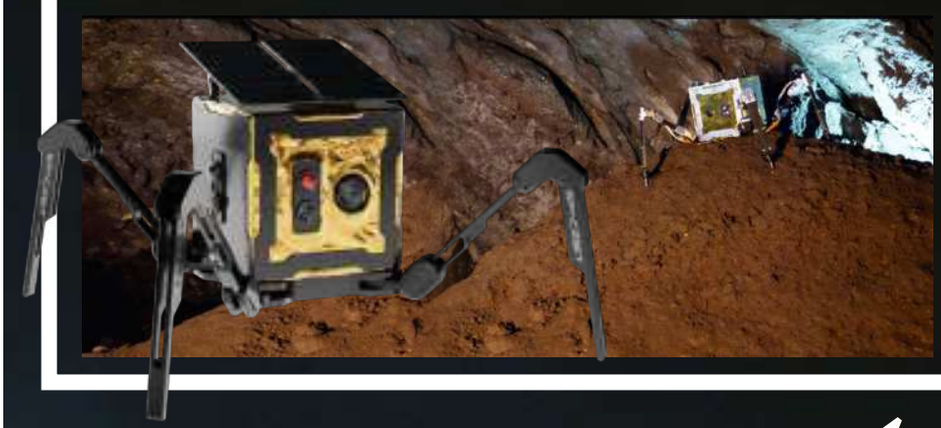
Other countries and organisations, too, have expressed their desire to return to the Moon. China, which has made great headway with its uncrewed Chang'e series of missions – even returning samples from the Moon in December 2020 – hopes to send humans there in the 2030s. The European Space Agency (ESA), meanwhile, has also expressed a desire to go to the Moon, perhaps in partnership with NASA. And let's not forget private companies like SpaceX. The Moon is very much back on the agenda, and who knows what the future might hold.

Commercial Moon missions

2022 onwards

A variety of commercial companies are hoping to reach the Moon in the near future. The closest of those is the Pennsylvania-based company Astrobotic, which hopes to launch its Peregrine lander to the Moon in 2022. It is set to land in a region called Lacus Mortis, or the 'Lake of Death', and it will have 14 different scientific payloads on board. One of the things it will carry there will be a small robotic spider, from the UK company Spacebit, which is designed to walk around on the surface of the Moon and send high-definition video back to Earth, along with other useful data. Spacebit ultimately hopes to launch many more of these robots to explore some of the Moon's secrets, like its underground caves and tunnels.

Elsewhere, another US company called Intuitive Machines is hoping to launch its first mission to the Moon in early 2022. Its Nova-C lander is designed to take up to 100 kilograms of cargo to the lunar surface, which will include science experiments funded by NASA for its Artemis program. It is set to launch on a SpaceX Falcon 9 rocket to the Moon, and will touch down in a region called Oceanus Procellarum – or 'Ocean of Storms'. These missions could be just the start. With access to space becoming easier and cheaper, more companies might well reach the Moon in the not too distant future. Could we one day have fully functioning bases on our lunar neighbour thanks to these pioneering missions? Time will tell.



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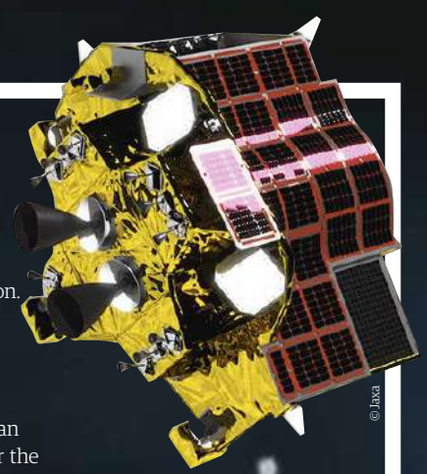
SLIM

Early 2022

The Smart Lander for Investigating Moon (SLIM) is Japan's first attempt at landing on the surface of the Moon. Developed by the Japan Aerospace Exploration Agency (JAXA), it's hoped that SLIM could launch in early 2022.

The mission is designed to practice performing very precise landings on the Moon, using facial recognition technology to identify lunar craters to touch down with an accuracy of 100 meters. The lander will touch down near the Marius Hills 'Hole', a possible lava tube on the lunar surface where lava once flowed, leaving a hollow cavern behind. Demonstrating this accurate landing is a key goal for the mission. JAXA hopes to use the technology from SLIM on future missions, including sending another uncrewed spacecraft to the surface of the Moon, picking up a sample, and returning it to Earth at some point in future – a feat so far accomplished by the US, Russia, and China.

Japan is currently working with India on such a mission, called the Lunar Polar Exploration Mission (LUPEX), which plans to send a lander with a rover to the south pole of the Moon in 2024. This would use the technology developed on SLIM, and India's previous experience at building lunar landers. That same year, Japan also hopes to send a mission called the Martian Moons Exploration (MMX) to the Martian moon Phobos. The mission will be the first to not only attempt a landing on Phobos, but picking up a sample and returning it to Earth in 2028.



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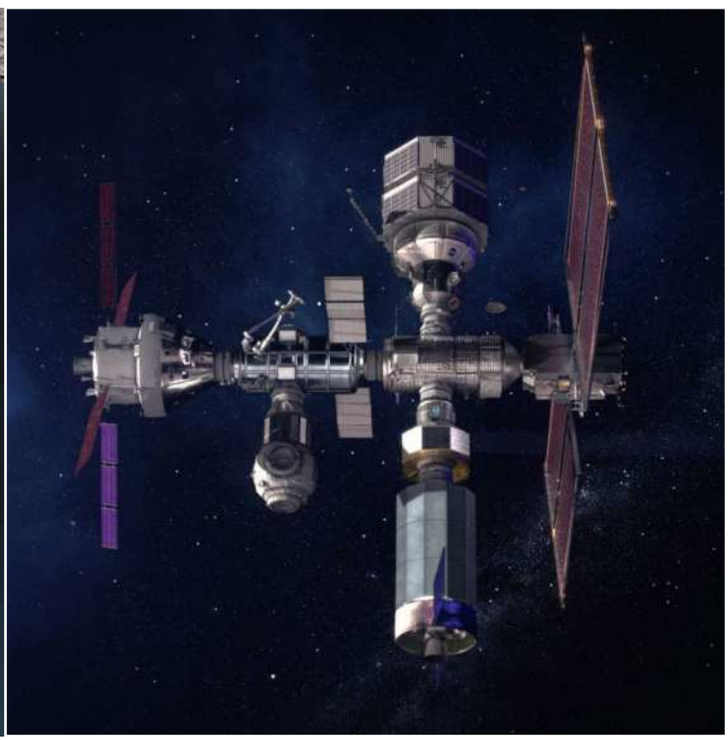
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Artemis programme

December 2017 - present

In the Sixties and Seventies, the US landed astronauts on the Moon for the first - and to date, only - time in history. In total, 12 humans set foot on the Moon from 1969 to 1972 as part of NASA's Apollo programme, but since Gene Cernan and Jack Schmitt left the surface of the Moon on Apollo 17 on 14 December 1972, no humans have returned. Now, NASA is hoping to change that. It has been developing a bold new lunar exploration program, called Artemis, that it hopes will not only land humans on the Moon again, but also provide a stepping stone for future missions to Mars. The programme was started with the goal of landing a man and the first woman on the Moon in 2024.

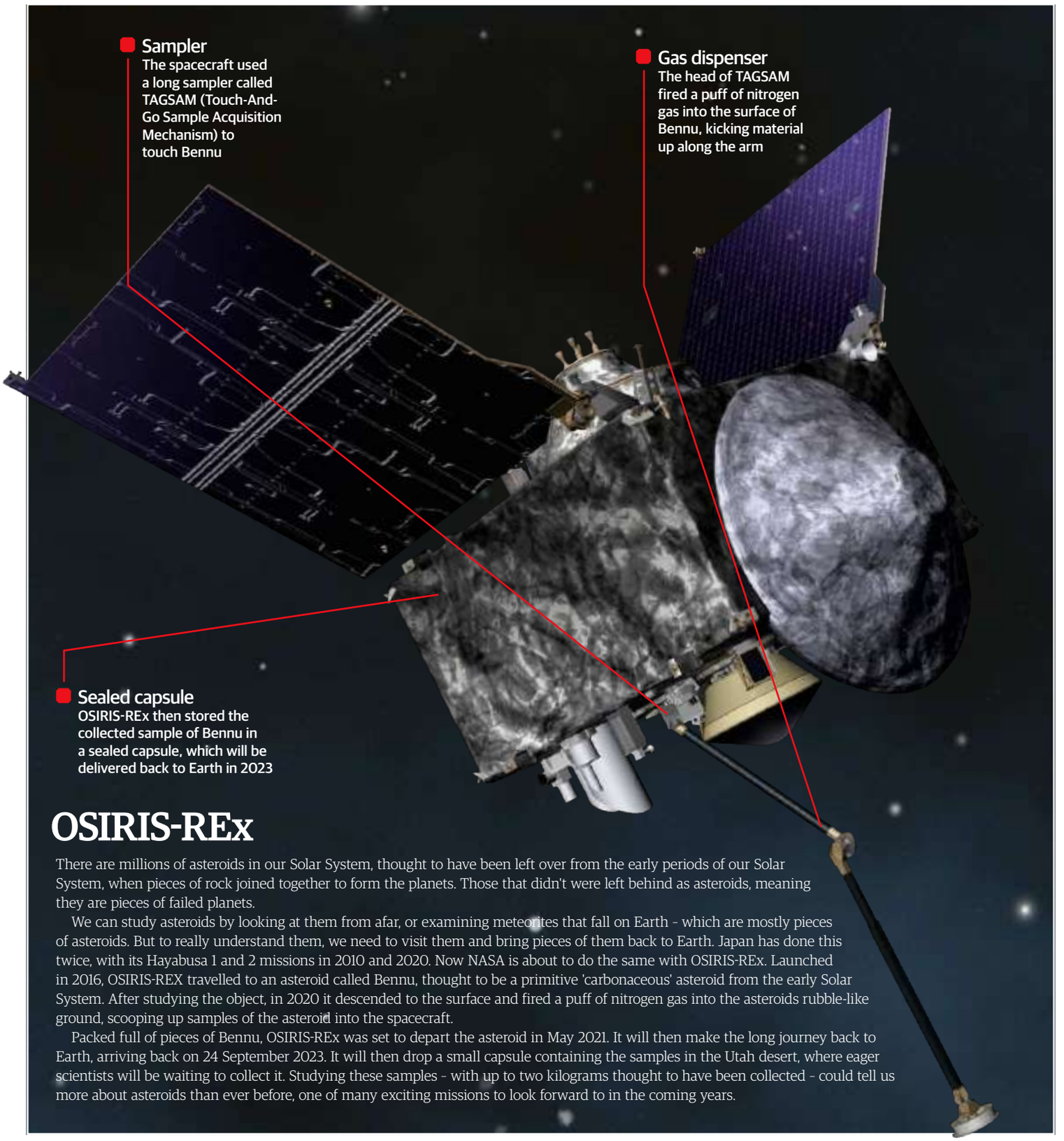
The project would use NASA's new mega rocket it is developing, called the Space Launch System (SLS), to deliver humans to the Moon. Using an orbiting outpost called the Lunar Gateway, humans would then be able to make regular trips to and from the Moon on landers developed by private companies. However, with President Biden's victory over Trump in the Presidential election of 2020, the future of Artemis is currently up in the air. It's unclear if NASA will pursue this goal, or shift focus more to other destinations such as Mars. For the time being, however, the Lunar Gateway is pressing ahead - and time will tell if that culminates in a return of humans to the Moon as well.



© NASA

Exploring asteroids

Several missions are planning to explore asteroids like never before, unveiling secrets of the Solar System



OSIRIS-REx

There are millions of asteroids in our Solar System, thought to have been left over from the early periods of our Solar System, when pieces of rock joined together to form the planets. Those that didn't were left behind as asteroids, meaning they are pieces of failed planets.

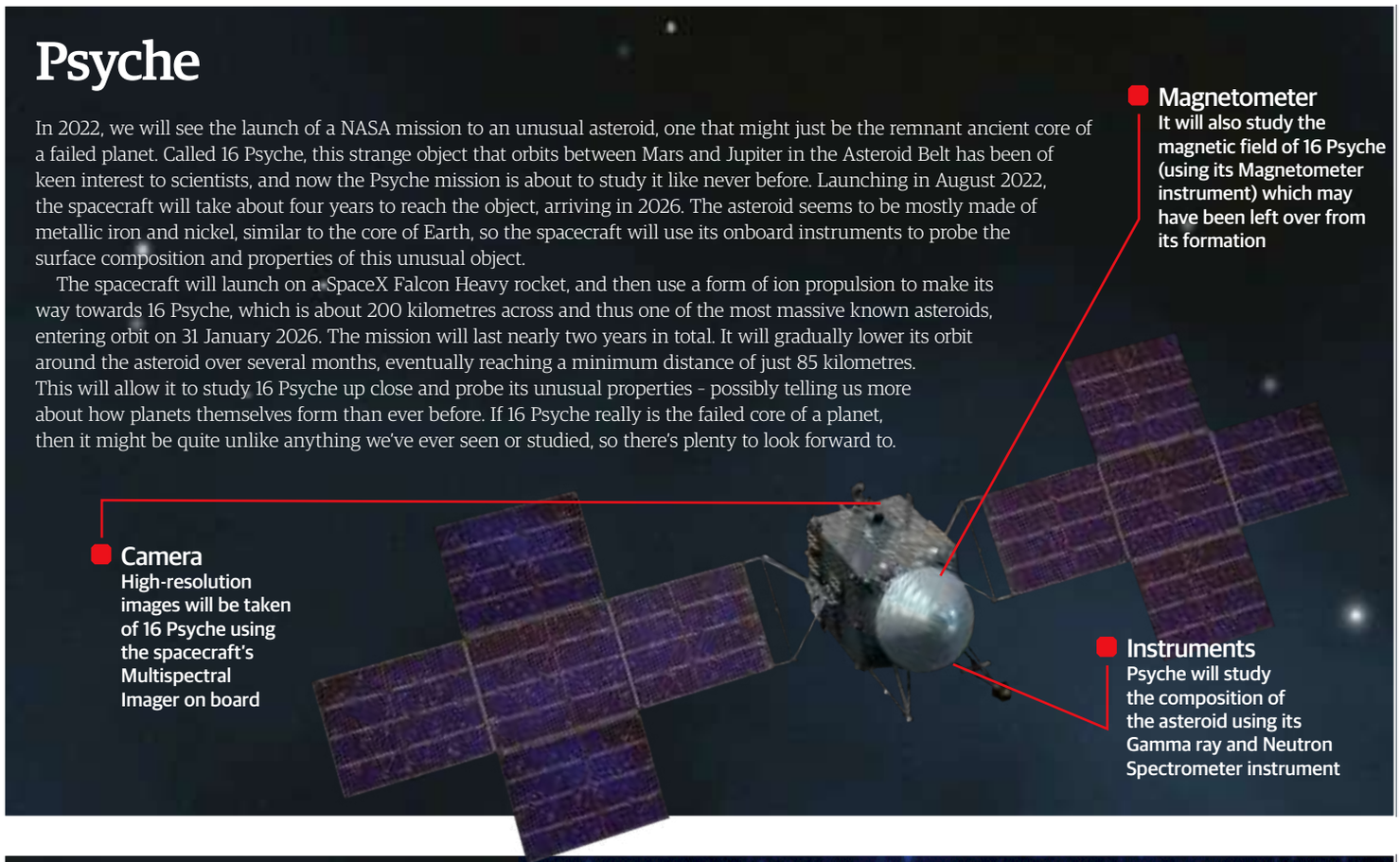
We can study asteroids by looking at them from afar, or examining meteorites that fall on Earth - which are mostly pieces of asteroids. But to really understand them, we need to visit them and bring pieces of them back to Earth. Japan has done this twice, with its Hayabusa 1 and 2 missions in 2010 and 2020. Now NASA is about to do the same with OSIRIS-REx. Launched in 2016, OSIRIS-REX travelled to an asteroid called Bennu, thought to be a primitive 'carbonaceous' asteroid from the early Solar System. After studying the object, in 2020 it descended to the surface and fired a puff of nitrogen gas into the asteroids rubble-like ground, scooping up samples of the asteroid into the spacecraft.

Packed full of pieces of Bennu, OSIRIS-REx was set to depart the asteroid in May 2021. It will then make the long journey back to Earth, arriving back on 24 September 2023. It will then drop a small capsule containing the samples in the Utah desert, where eager scientists will be waiting to collect it. Studying these samples - with up to two kilograms thought to have been collected - could tell us more about asteroids than ever before, one of many exciting missions to look forward to in the coming years.

Psyche

In 2022, we will see the launch of a NASA mission to an unusual asteroid, one that might just be the remnant ancient core of a failed planet. Called 16 Psyche, this strange object that orbits between Mars and Jupiter in the Asteroid Belt has been of keen interest to scientists, and now the Psyche mission is about to study it like never before. Launching in August 2022, the spacecraft will take about four years to reach the object, arriving in 2026. The asteroid seems to be mostly made of metallic iron and nickel, similar to the core of Earth, so the spacecraft will use its onboard instruments to probe the surface composition and properties of this unusual object.

The spacecraft will launch on a SpaceX Falcon Heavy rocket, and then use a form of ion propulsion to make its way towards 16 Psyche, which is about 200 kilometres across and thus one of the most massive known asteroids, entering orbit on 31 January 2026. The mission will last nearly two years in total. It will gradually lower its orbit around the asteroid over several months, eventually reaching a minimum distance of just 85 kilometres. This will allow it to study 16 Psyche up close and probe its unusual properties – possibly telling us more about how planets themselves form than ever before. If 16 Psyche really is the failed core of a planet, then it might be quite unlike anything we've ever seen or studied, so there's plenty to look forward to.

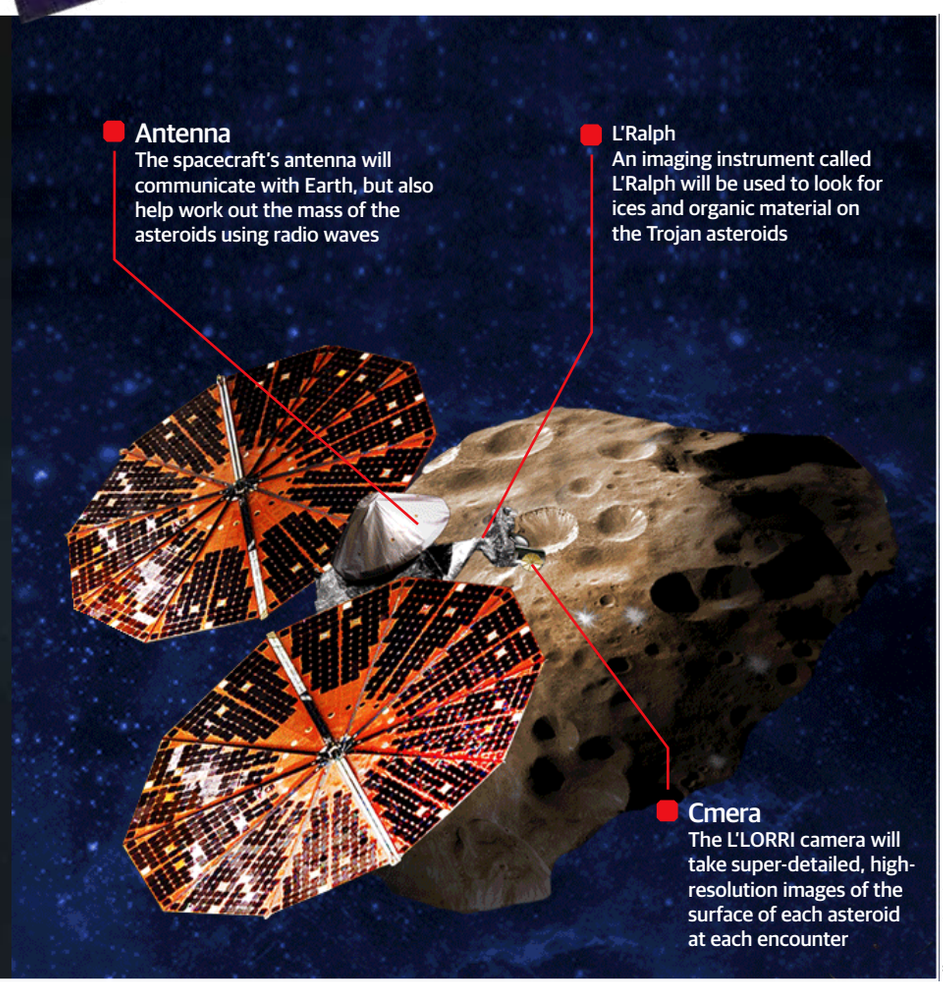


Lucy

In our Solar System, there are a group of asteroids that we've seen, but never observed. Called the Trojan asteroids, they orbit in front and behind Jupiter in two groups, and are thought to be remnants of the formation of the outer planets.

NASA's Lucy mission, which launched in October 2021, will be the first mission to ever visit some of these asteroids. Over 12 years, the spacecraft is set to fly past six of the Trojan asteroids, as well as a bonus asteroid in the Asteroid Belt between Mars and Jupiter, over the course of its mission running until 2033. Using its onboard instruments, the spacecraft will study the geology and composition of the different asteroids that it flies past at close range. It will aim to work out the mass and density of each object too, hopefully telling us more about how they formed, and what role they played – if any – in the formation of the gas giants.

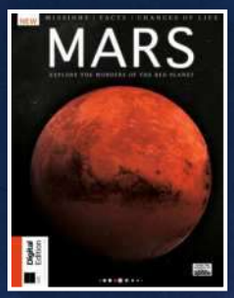
The mission will visit four Trojan asteroids in the group orbiting ahead of Jupiter from 2027 to 2028, before departing and flying back past Earth's orbit to study two in the group trailing Jupiter in 2033. The mission is named after the famous 'Lucy' fossilised skeleton which told us about early human history, it's hoped this spacecraft could similarly tell us more about the early history of our Solar System. It'll definitely be one mission to watch and keep an eye on.



All images © NASA



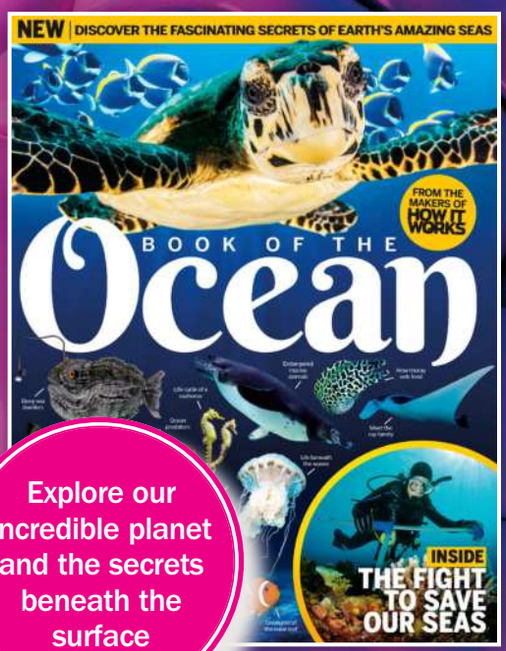
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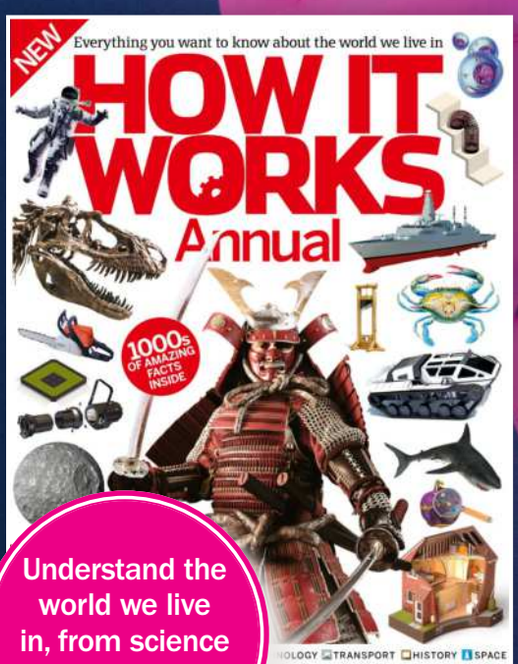
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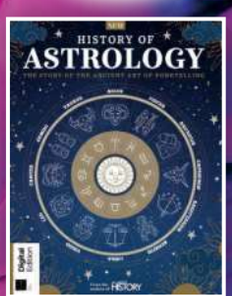








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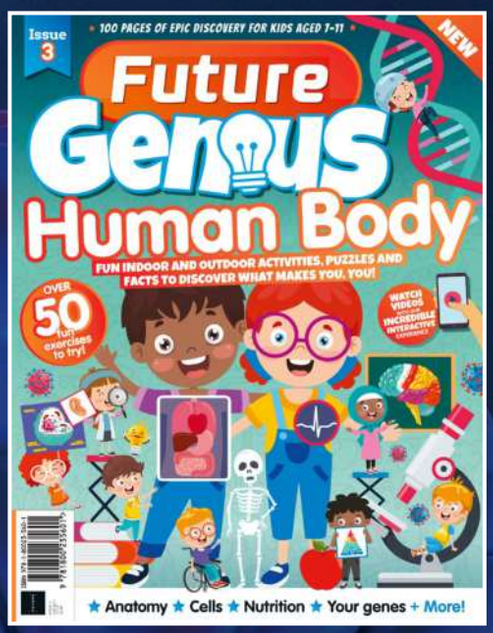


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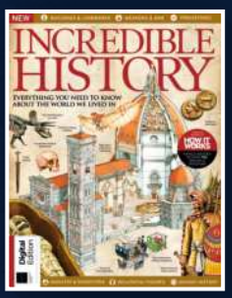
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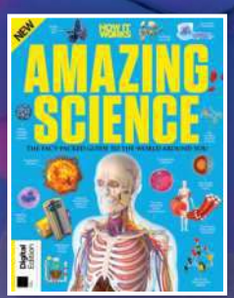






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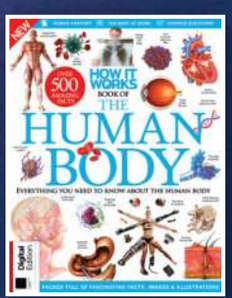












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